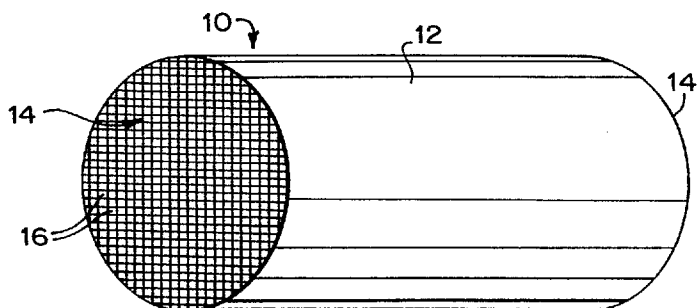




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(54) **CATALYSEUR DE NO_x ET PROCEDE D'UTILISATION**
(54) **NO_x CATALYST AND METHOD OF USING THE SAME**



(57) Une composition de limitation des émissions de NO_x comprend un catalyseur de limitation des émissions de NO_x et un solvant de NO_x disposés de façon proche mais séparés l'un de l'autre sur un support réfractaire commun (10). Le solvant de NO_x comprend un composé métallique oxygéné basique et, à titre facultatif, des oxydes cériques. Le catalyseur de limitation des émissions NO_x contient un composant métallique catalytique, à base de platine, qui est séparé du sorbant de NO_x, lequel peut être constitué d'un ou plusieurs oxydes, carbonates ou hydroxydes métalliques ou d'oxydes métalliques mixtes. Le composant métallique catalytique et le sorbant de NO_x au moins doivent recouvrir ou constituer des particules séparées qui peuvent être soit mélangées soit disposées en couches distinctes (20a, 20b) sur le support (10). Un procédé de limitation des émissions de NO_x, qui recourt à cette composition, consiste à régler périodiquement le flux gazeux d'admission pour que sa composition passe entre des cycles de fonctionnement pauvre et stoechiométrique/riche.

(57) A NO_x abatement composition comprises a NO_x abatement catalyst and a NO_x sorbent material which are dispersed in proximity to, but segregated from, each other on a common refractory carrier member (10). The NO_x sorbent material comprises a basic oxygenated metal compound and optionally further comprises ceria. The NO_x abatement catalyst contains a catalytic metal component including a platinum metal catalytic component. The catalytic metal component is segregated from the NO_x sorbent material, which may be one or more of metal oxides, metal carbonates, metal hydroxides and mixed metal oxides. At least the catalytic metal component and the NO_x sorbent material must be on, or comprise separate, particles; the particles may either be admixed or may be disposed in separate layers (20a, 20b) on the carrier member (10). A NO_x abatement method employs the composition and includes periodically adjusting the gas being treated between lean and stoichiometric/rich operating cycles.

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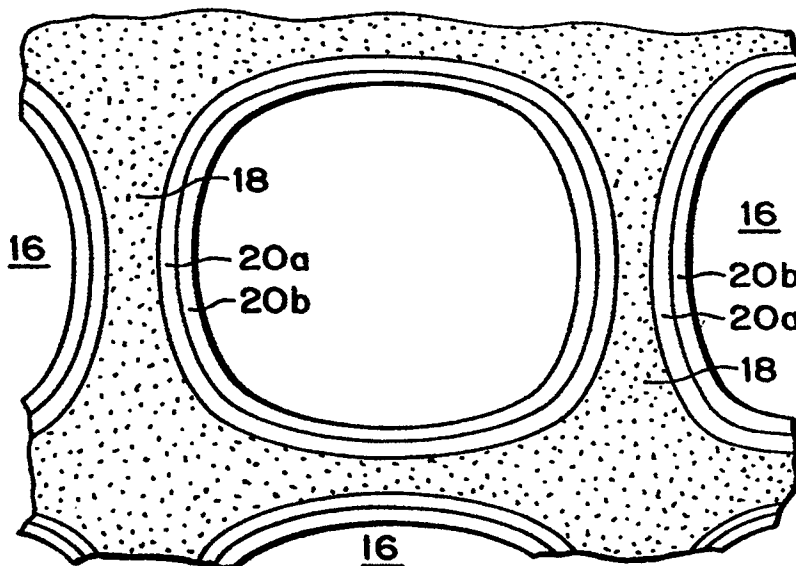
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(54) Title: NO_x CATALYST AND METHOD OF USING THE SAME

(57) Abstract

A NO_x abatement composition comprises a NO_x abatement catalyst and a NO_x sorbent material which are dispersed in proximity to, but segregated from, each other on a common refractory carrier member (10). The NO_x sorbent material comprises a basic oxygenated metal compound and optionally further comprises ceria. The NO_x abatement catalyst contains a catalytic metal component including a platinum metal catalytic component. The catalytic metal component is segregated from the NO_x sorbent material, which may be one or more of metal oxides, metal carbonates, metal hydroxides and mixed metal oxides. At least the catalytic metal component and the NO_x sorbent material must be on, or comprise separate, particles; the particles may either be admixed or may be disposed in separate layers (20a, 20b) on the carrier member (10). A NO_x abatement method employs the composition and includes periodically adjusting the gas being treated between lean and stoichiometric/rich operating cycles.



NO_x CATALYST AND METHOD OF USING THE SAMEBACKGROUND OF THE INVENTION

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Field of The Invention

The present invention is broadly concerned with NO_x abatement, especially with NO_x abatement in the exhaust gas of lean-burn internal combustion engines. More specifically, the present invention is concerned with a novel composition comprising a combination of a NO_x trap (sorbent material) and a NO_x abatement catalyst, and to a method of using the same.

15 Related Art

It is well-known in the art to utilize catalyst compositions, such as those commonly referred to as three-way conversion catalysts ("TWC catalysts") to treat the exhaust gases of internal combustion engines. Such catalysts have been found to successfully promote both the oxidation of unburned hydrocarbons ("HC") and carbon monoxide ("CO") and the reduction of nitrogen oxides ("NO_x") in the exhaust gas, provided that the engine is operated at or close to stoichiometric air/fuel conditions. However, many present day engines, especially gasoline-fueled engines used for passenger automobiles and the like, are designed to operate under lean conditions at least part of the time as a fuel economy measure. That is, the ratio of air to fuel in the combustion mixture supplied to the engine is maintained above the stoichiometric ratio so that the resulting exhaust gases are "lean", i.e., the exhaust gases are relatively high in oxygen content and relatively low in reductants content, e.g., HC, CO and/or hydrogen.

Although lean burn engines provide enhanced fuel economy, they have the disadvantage that conventional TWC catalysts cannot adequately abate the NO_x component of pollutants in the gas stream. The art has devoted some effort to developing catalysts specifically designed to

treat the exhaust of lean burn engines. One such effort is described in the publication Environmental Catalysis For A Better World And Life, Proceedings of the 1st World Congress at Pisa, Italy, May 1-5, 1995, published by the Societa Chimica Italiana of Rome, Italy. At pages 45-48 of the publication, there is an article entitled "The New Concept 3-Way Catalyst For Automotive Lean-Burn Engine Storage and Reduction Catalyst", by Takahashi et al (below referred to as "the Takahashi et al paper"). This article discloses the preparation of catalysts by impregnating precious metals, mainly platinum, and various alkaline and alkaline earth metal oxides, mainly barium oxide, and rare earth oxides on supports, mainly alumina. These catalysts were employed for NO_x purification of actual and simulated exhaust gases. At page 47 of the article, there is both shown graphically in Figure 5 and discussed in paragraph 3.1.1., "NO_x Storage Mechanism", the concept of employing NO_x storage compounds in conjunction with the catalytic (platinum) component, with both the NO_x storage compounds and the catalytic component dispersed on a common support material. It is stated that "When precious metals were separated from the NO_x storage compounds on these catalysts, the NO_x storage amount drastically decreased." Paragraph 3.1.1. therefore teaches that the NO_x storage compound and the platinum catalyst should be intimately admixed by being disposed on the same increment of, e.g., alumina, support as described in the catalyst preparation procedure described in paragraph 2 (page 45) and illustrated in Figure 5.

In paragraph 3.1, page 46, testing of the catalysts is described as being carried out with simulated exhaust gases alternately under oxidizing and reducing conditions. The conclusion is drawn on the last sentence on page 46, that NO_x was stored in the catalyst under oxidizing conditions and that the stored NO_x was then reduced to nitrogen under stoichiometric and reducing conditions.

SAE paper 950809 published by the Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, and en-

titled Development of New Concept Three-Way Catalyst for Automotive Lean-Burn Engines, by Naoto Miyoshi et al, was delivered at the International Congress and Exposition, Detroit, Michigan, February 27-March 2, 1995. This paper, referred to below as "the SAE paper", which has authors in common with the above-mentioned Takahashi et al paper, contains a disclosure which is substantially the same as, but is more detailed than, that of the Takahashi et al paper. At page 123 of the SAE paper a correlation between basicity of the elements used as NO_x storage material and NO_x storage capacity is discussed as is NO_x adsorption by complex oxides such as YBa₂Cu₃O_y and CuO-BaO. The discussion of mixed oxides is made with reference to items 6 and 7 of the references cited at the end of the SAE paper.

The references are "Uptake of NO gas by YBa₂Cu₃O_y" by K. Tabata et al, Chem. Lett., 1988, pp. 799-802 and "NO removal by adsorption into BaO-CuO binary oxides" by M. Machida et al, J. Chem. Soc. Chem. Commun. 1990, pp. 1165-1166. At page 125 of the SAE paper, there is a comparison of two catalysts. One catalyst comprises (a) noble metal impregnated on one increment of alumina and the NO_x storage component impregnated on alumina, and the other catalyst comprises (b) both noble metal and the storage component impregnated on the same increment of alumina. The SAE paper states that catalyst (a) stored a very small amount of NO_x as compared to catalyst (b) and concludes that the "storage amount increases when the noble metal is in the proximity of the storage component".

U.S. Patent 5,202,300, "Catalyst For Purification of Exhaust Gas", issued on April 13, 1993, to M. Funabiki et al, discloses a catalyst composition comprising a refractory support having deposited thereon an active layer containing a palladium and rhodium catalytic metal component dispersed on alumina, a cerium compound, a strontium compound, and a zirconium compound. (See the Abstract.) This patent discloses the preparation of the catalyst by impregnating alumina particles with palladium and rhodium and then combining the impregnated alumina with compounds

such as cerium nitrate, strontium acetate hemi-hydrate and zirconyl acetate together with acetic acid and deionized water in a ball mill, and crushing and mixing the mixture to provide a slurry which is applied to a monolithic, cylindrical cordierite carrier. See columns 3-5 of the Funabiki et al Patent, especially Example 1 which discloses that the strontium compound is solubilized in the acidified water and impregnated into the alumina support particles together with the palladium and rhodium catalytic metal components. Example 1 as Funabiki et al, like the Takahashi et al and SAE papers referred to above, impregnates both the alkaline earth metal compound (a strontium compound in the case of Funabiki et al), and the palladium and rhodium catalytic metal components into the same increment of (alumina) support material. However, Example 2 of Funabiki et al substitutes strontium hydroxide for the strontium acetate and the limited solubility of strontium hydroxide suggests that it remains in bulk form in the finished product, admixed with the palladium and rhodium-impregnated alumina.

SUMMARY OF THE INVENTION

Generally, the present invention provides a composition containing a NO_x sorbent material and a NO_x abatement catalyst, the latter including one or more catalytic metal components essentially including a platinum catalytic metal component. The abatement catalyst may optionally include one or more other platinum group metal components. The composition is characterized by the catalytic metal components being segregated from the NO_x sorbent material at least to the extent that the catalytic metal components and the NO_x sorbent material are not dispersed on the same increment of support material. Preferably, the NO_x sorbent material is a bulk material and it is substantially free of any catalytic metal components dispersed thereon. Inasmuch as ceria is not effective for NO_x abatement it is not considered to be a catalytic metal component and in certain embodiments of the invention ceria may optionally

be combined with the NO_x sorbent material.

Specifically, in accordance with the present invention there is provided a composition for NO_x abatement in a gas stream, the composition comprising a NO_x abatement catalyst and a NO_x sorbent material disposed in proximity to each other on a common refractory carrier member. The NO_x abatement catalyst comprises a catalytic metal component comprised of a platinum catalytic metal component. The catalytic metal component is dispersed on a first refractory support material, e.g., alumina. The NO_x sorbent material comprises at least one basic oxygenated metal compound, e.g., strontium oxide or strontium hydroxide, which is segregated from the platinum group metal catalytic component, at least to the following extent. When the NO_x sorbent material is dispersed on a refractory support material, the catalytic metal component and the NO_x sorbent material are not dispersed on the same increment of refractory support material. When the NO_x sorbent material is present in bulk form, the catalytic metal component is not impregnated into the bulk NO_x sorbent material.

In one aspect of the invention the catalytic metal component further comprises at least one other platinum group metal catalytic component in addition to the platinum catalytic metal component.

In another aspect of the invention, the NO_x sorbent material is selected from the group consisting of one or more of metal oxides, metal carbonates, metal hydroxides and mixed metal oxides. Optionally, the NO_x sorbent material may further comprise ceria, e.g., bulk ceria.

Yet another aspect of the invention provides that the NO_x sorbent material comprises a mixed metal oxide selected from the group consisting of one or more of barium strontium tungstate, barium strontium niobate, strontium titanate, barium zirconate, barium silicate and barium strontium titanate.

In another aspect of the invention, the NO_x sorbent material is selected from the group consisting of one or

WO 97/02886

PCT/US96/03491

-6-

more of metal oxides, metal hydroxides, metal carbonates, and mixed metal oxides, wherein the metals of the metal oxides, metal hydroxides and metal carbonates and at least one of the metals of the mixed metal oxides are selected
5 from the group consisting of lithium, sodium, potassium, rubidium, cesium, magnesium, calcium, strontium and barium.

One aspect of the present invention provides that the NO_x abatement catalyst is admixed with the NO_x sorbent material;
10 another aspect of the invention provides that the NO_x abatement catalyst is disposed as a first discrete layer on the refractory carrier member and the NO_x sorbent material is disposed as a second discrete layer on the refractory carrier member. Yet another aspect of the in-
15 vention provides that the first discrete layer (the NO_x abatement catalyst) comprises an underlayer disposed on the carrier member and the second discrete layer (the NO_x sorbent material) comprises an overlayer superposed on the underlayer. In any case, the discrete layers may be in
20 direct contact one with the other or an intervening layer, e.g, alumina, may be interposed between the two discrete layers.

Still other aspects of the present invention provide one or more of the following features: the NO_x abatement
25 catalyst may comprise, in addition to the platinum catalytic metal component, one or more other platinum group metal catalytic components; the refractory support material may comprise a refractory metal oxide; and the NO_x sorbent material may comprise a metal oxide selected from the
30 group consisting of oxides of one or more of magnesium, calcium, strontium and barium.

Yet another aspect of the invention provides that the refractory carrier, e.g, made of cordierite, comprises a body having a plurality of gas flow passages extending
35 therethrough, the passages being defined by passage walls, and the NO_x abatement catalyst and the NO_x sorbent material, e.g., the first and second layers, are disposed on the passage walls.

Still another aspect of the invention provides that the refractory carrier comprises a body of carrier beads retained within a gas-permeable container. In such case, the NO_x abatement catalyst and the NO_x sorbent material, e.g., the first and second layer may be arranged so that the first layer is disposed on one increment of carrier beads and the second layer is disposed on a second increment of carrier beads, with the first and second increments of carrier beads admixed within the container. Alternatively, the first and second layers may be disposed on the same increment of carrier beads or the NO_x abatement catalyst and the NO_x sorbent material may also be mixed on the same increment of carrier beads.

In accordance with the method aspect of the present invention there is provided a method of NO_x abatement comprising contacting a gas stream containing NO_x with a NO_x abatement composition as defined above. The method includes periodically adjusting the composition of the gas stream between lean and stoichiometric/rich conditions to thereby provide alternating lean operating condition periods and stoichiometric/rich operating condition periods, and maintaining NO_x abatement conditions during the stoichiometric/rich operating condition periods, whereby during the lean operating periods the NO_x abatement catalyst promotes sorption of NO_x by the NO_x sorbent material and during the rich operating periods the NO_x abatement catalyst promotes reduction of NO_x to nitrogen.

As used herein and in the claims, the following terms, whether used in singular or plural form, have the indicated meanings.

Reference herein and in the claims to the NO_x abatement catalyst and the NO_x sorbent material being "in proximity to each other on a common refractory carrier member" means that the NO_x abatement catalyst and the NO_x sorbent material are either admixed with each other, or disposed in respective superposed layers, on the same carrier member.

When a component, such as ceria or the NO_x sorbent

material, is described as a "bulk" component, this means that the component is present as solid particles thereof. These particles are usually very fine, on the order of at least 90 percent of the particles being from about 5 to 15
5 microns in diameter. The term "bulk" is intended to distinguish from the situation in which a component is "dispersed" on a refractory support material by being impregnated into the support material from a solution or other liquid dispersion of the component. For example, it is
10 well-known in the art to stabilize activated alumina (predominantly γ -alumina), which is used as a refractory support material, against thermal degradation in TWC and other catalyst compositions by impregnating the particles of alumina with the solution of a soluble cerium compound
15 such as a solution of cerium nitrate. After impregnation, the alumina particles are dried and calcined in air to convert the impregnated cerium nitrate to ceria. The resultant ceria is thus "dispersed" onto and, to a greater or lesser extent, within a surface layer of the solid par-
20 ticles of the alumina. The dispersed ceria is not present in bulk form, because bulk ceria comprises fine, solid particles of ceria.

Reference to components which are not being dispersed on "the same increment" or "increments" of refractory sup-
25 port material simply means that the components are not dispersed on the same particles of refractory support materials. For example, consider a situation in which a catalytic metal component is dispersed onto one batch of alumina particles and a NO_x sorbent material is dispersed
30 onto a second, different batch of alumina particles. This situation would result in the catalytic metal component and the NO_x sorbent material being dispersed on "different increments" of alumina. This situation differs from that described, for example, in the aforementioned Funabiki et
35 al U.S. Patent 5,202,300 wherein, following the procedure of Example 1 thereof, the palladium and rhodium catalytic metal components are dispersed onto alumina particles and thereafter a strontium compound (as well as other com-

pounds) are dispersed onto the same alumina particles onto which the palladium and rhodium catalytic components are dispersed. In that case, the platinum/rhodium and strontium compounds are dispersed onto the same increment of

5 alumina.

Reference to a "catalytic metal component" means a catalytic metal, such as a platinum group metal, whether the metal is present as the element, or alloy or a compound, e.g., an oxide, and which is effective to catalyze

10 NO_x abatement in a gas stream.

The term "platinum group metals" means and includes platinum, rhodium, palladium, ruthenium, iridium and osmium.

15 The term "washcoat" has its usual meaning in the art of a thin, adherent coating of a catalytic or other material applied to a refractory carrier material such as a honeycomb-type carrier member, and which is porous to permit the passage therethrough of the gas stream being treated.

20 The term "stoichiometric/rich" is used with reference to the condition of the gas stream being treated and refers collectively to the stoichiometric and rich operating conditions of the gas stream.

25 The term "gas stream" means a stream of gaseous constituents, such as the exhaust of an internal combustion engine, which may contain entrained non-gaseous components such as liquid droplets, solid particulates and the like.

30 The term "mixed metal oxide" means bimetallic or multi-metallic oxygen compounds, such as Ba₂SrWO₆, which are true compounds and is not intended to embrace mere mixtures of two or more individual metal oxides such as a mixture of SrO and BaO.

BRIEF DESCRIPTION OF THE DRAWINGS

35 Figure 1 is a perspective view of a catalyst/trap composition comprising a honeycomb-type refractory carrier member in accordance with one embodiment of the present invention;

Figure 1A is a partial cross-sectional view enlarged relative to Figure 1 and taken along a plane parallel to the end faces of the carrier of Figure 1;

Figure 1B is a view enlarged relative to Figure 1A of one of the gas flow passages shown in Figure 1A;

Figure 1C is a cross-sectional schematic partial view of a carrier body comprising a gas-permeable container within which are disposed a plurality of carrier beads in accordance with one embodiment of the present invention; and

Figures 2-12 show various graphs plotting test data comprising (except for Figure 2A) NO_x removal versus the gas stream temperature at the inlet to the composition being tested, for certain embodiments of the present invention and for certain comparative compositions; Figure 2A plots NO_x removal versus time.

DETAILED DESCRIPTION OF THE INVENTION **AND SPECIFIC EMBODIMENTS THEREOF**

Contrary to some teachings of the prior art, for example, the discussion in the above-mentioned Takahashi et al and SAE papers, it has surprisingly been found that an exceedingly effective and durable composition for the abatement of NO_x in a gas stream is provided by a composition comprising a NO_x sorbent material and one or more catalytic metal components, essentially including a platinum catalytic metal component, in which the NO_x sorbent material is in proximity to but segregated from the catalytic metal component or components. In one embodiment of the invention, both the catalytic metal component or components and the NO_x sorbent material or materials are dispersed onto different respective increments or batches of support material, such as activated alumina. In this embodiment, the NO_x sorbent material is dispersed onto a first batch of refractory support material to provide a "supported NO_x abatement material" and the catalytic metal component is dispersed onto a second batch of refractory support material. Ceria, either in dispersed or bulk

form, is often used as an oxygen-storage component of three-way conversion catalysts and therefore may be a component of the NO_x abatement catalyst, although the NO_x abatement catalyst will in such case necessarily also
5 contain other catalytic metal components effective for NO_x abatement.

In another embodiment of the invention which is preferred because it is believed that it provides enhanced NO_x sorption and release characteristics, the NO_x sorbent
10 material is provided in bulk form, i.e., as discrete fine particles of the NO_x sorbent material, to provide a "bulk NO_x sorbent material". In this embodiment, the composition comprises refractory support material such as particles of activated alumina impregnated with the catalytic
15 metal component, and particles of the NO_x sorbent material, i.e., in bulk form.

Whichever of the two above-described embodiments of the present invention is employed, either embodiment may be employed as a mixture of the NO_x abatement catalyst and
20 NO_x sorbent material or as discrete layers of the NO_x abatement catalyst and NO_x sorbent material. The requisite segregation of the abatement catalyst and sorbent material is attained in a mixture of the NO_x abatement catalyst with either the supported NO_x sorbent material or
25 bulk NO_x sorbent material because in both cases the catalytic metal component is supported on particles of support material which do not also support NO_x sorbent material and the NO_x sorbent material does not support any catalytic metal component. Of course, when the NO_x sorbent
30 material, whether supported or bulk, is disposed in a discrete layer separate from a second discrete layer of NO_x abatement catalyst, a still higher degree of segregation is attained. The degree of segregation may be further enhanced by disposing an intermediate washcoat layer between
35 the layers of abatement catalyst and support material. However, it has been found that an excessive degree of segregation of the (1) NO_x abatement catalyst and (2) the NO_x sorbent material, such as that attained by depositing

(1) and (2) on respective, separate carrier members dispersed in series gas flow, yielded very poor results. The segregated components (1) and (2) are therefore, in accordance with the present invention, disposed on a common carrier member in proximity to each other.

In a specific embodiment, the composition of the present invention may comprise a refractory carrier member such as a honeycomb-type member comprising a unitary body made of a suitable material such as cordierite and having a plurality of fine, parallel gas flow passages extending therethrough from an inlet face to an outlet face of the member. The walls defining these fine gas flow passages may be coated in a manner well-known in the art with a washcoat comprising either a mixture of fine particles of the NO_x abatement catalyst and NO_x sorbent material, or the walls may be coated with a respective discrete layer of NO_x abatement catalyst and a respective discrete layer of NO_x sorbent material. The NO_x abatement catalyst is preferably disposed as a first or underlayer on the carrier with the NO_x sorbent material being disposed as a second overlayer superposed on the underlayer. Optionally, the two layers may be separated by an intermediate layer, such as an intermediate layer of one or more of alumina, zirconia, ceria, titania or other suitable refractory metal oxide. Alternatively, the two layers may be in "direct contact" with each other, by which is meant that there is no intervening layer of another material between the respective catalyst and sorbent material layers.

Figure 1 shows generally at 10 a refractory carrier member of generally cylindrical shape having a cylindrical outer surface 12, one end face 14 and an opposite end face, not visible in Figure 1, which is identical to end face 14. The junction of outer surface 12 with the opposite end face at its peripheral edge portion is indicated at 14' in Figure 1. Carrier member 10 has a plurality of fine, parallel gas flow passages 16 formed therein, better seen in enlarged Figure 1A. Gas flow passages 16 are formed by walls 18 and extend through carrier 10 from end

face 14 to the opposite end face thereof, the passages 16 being unobstructed so as to permit the flow of a fluid, e.g., a gas stream, longitudinally through carrier 10 via gas flow passages 16 thereof. As will be seen from Figures 1A and 1B walls 18 are so dimensioned and configured that gas flow passages 16 have a substantially regular polygonal shape, substantially square in the illustrated embodiment, but with rounded corners in accordance with U.S. Patent 4,335,023, issued June 15, 1982 to J.C. Dettling et al. A layer 20, which in the art and sometimes below is referred to as a "washcoat", is adhered to the walls 18 and, as shown in Figure 1B, may be comprised of a single layer comprising a mixture of NO_x abatement catalyst and NO_x sorbent material. Alternatively, as illustrated in Figure 1B, layer or washcoat 20 may comprise a first discrete layer or underlayer 20a and a second discrete layer or overlayer 20b superposed over first layer 20a. The first layer or washcoat 20a preferably is comprised of the NO_x abatement catalyst and the second layer or washcoat 20b is preferably comprised of the NO_x sorbent material and is superposed over layer 20a. However, the arrangement of the layers may be reversed, with the first layer 20a comprised of the NO_x sorbent material and the second layer 20b comprised of the NO_x abatement catalyst. For purposes of illustration, the thickness of layers 20, 20a and 20b are exaggerated in Figures 1A and 1B.

As shown in Figures 1-1B, the honeycomb-type carrier members include void spaces provided by the gas-flow passages, and the cross-sectional area of these passages and the thickness of the walls defining the passages will vary from one type of carrier member to another. Similarly, the weight of washcoat applied to such carriers will vary from case to case. Consequently, in describing the quantity of washcoat or catalytic metal component or other component of the composition, it is convenient to use units of weight of component per unit volume of catalyst carrier. Therefore, the units grams per cubic inch ("g/in³") and grams per cubic foot ("g/ft³") are used

WO 97/02886

PCT/US96/03491

-14-

herein to mean the weight of a component per volume of the carrier member, including the volume of void spaces of the carrier member.

The density of gas flow passages per unit surface
5 area of the end faces of the carrier member is expressed herein as the number of cells (passages) per square inch, or "cpsi".

Generally, the NO_x sorbent material comprises at least one basic oxygenated metal compound and, as indicated above, may either be dispersed onto a refractory support material such as activated alumina, or may be present in bulk form, i.e., as fine particles of the basic oxygenated metal compound. As used herein and in the claims, an "oxygenated metal compound" means a compound of
10 metal and oxygen which may or may not contain other elements. For example, the basic oxygenated metal compound may comprise one or more of a metal oxide, a metal carbonate, a metal hydroxide or a mixed metal oxide. The metal of such compounds (at least one of the metals in the case
15 of the mixed oxides) is preferably selected from the group consisting of one or more of lithium, sodium, potassium, rubidium, cesium, magnesium, calcium, strontium and barium. Strontium oxide has been found to be an especially useful NO_x sorbent material. The NO_x sorbent material
20 will be present in an amount calculated to provide adequate sorption for the intended use. A typical quantity of the basic metal oxygenated compound will be from about 0.05 to 3 g/in³.

The NO_x sorbent material may optionally include a
30 sulfur compound sorbent such as ceria, either as bulk ceria or as ceria dispersed into the particles of NO_x sorbent material. In the latter case, the NO_x sorbent material may be impregnated with a solution of a soluble cerium salt such as cerium nitrate and then dried and
35 heated in air to convert the cerium nitrate to cerium oxide (ceria). It has been found that when present in either bulk or dispersed form, ceria facilitates coating the carrier member with a washcoat of the NO_x sorbent material

and also protects the basic oxygenated metal compounds comprising the NO_x sorbent material from poisoning by sulfur oxides which may be present in the gas stream being treated as the sulfur oxides are preferentially sorbed on the ceria. The NO_x sorbent material may thus advantageously contain ceria in a weight ratio of ceria to NO_x sorbent material of from about 0.1 to 100:1. Typically, ceria may be present in the composition in the amount of from about 0.05 to 1.0 g/in³, as CeO_2 . The NO_x sorbent material may also contain a binder such as alumina to enhance adherence of the NO_x sorbent material to the carrier member.

The NO_x abatement catalyst may comprise any catalyst which will catalyze the reduction of NO_x in the presence of a suitable reductant, usually hydrocarbons or CO in the case of treating the exhaust from an internal combustion gasoline engine. Without intending to be bound by any particular theory, it is believed that the platinum catalytic metal component of the NO_x abatement catalyst of the present invention serves a number of functions, including promoting the sorption of NO_x by the NO_x sorbent material during lean phase operation. In addition to catalyzing reduction of NO_x during rich phase operation the platinum catalytic metal component is also believed to catalyze some NO_x reduction during at least a part of the lean phase operation.

The NO_x abatement catalyst may comprise a suitable catalyst containing a platinum catalytic metal component and, optionally, one or more other platinum group metal catalytic components. Typically, these will include one or more of rhodium and palladium although other platinum group metal components may also be employed. A suitable NO_x abatement catalyst for utilization in accordance with the present invention is a conventional TWC catalyst which usually comprises one or more platinum group metal components including a platinum component dispersed on a refractory support. The refractory support is typically a refractory metal oxide such as activated alumina. TWC

catalysts may also include a so-called oxygen storage component which may comprise bulk ceria or a base metal oxide such as an oxide of nickel, iron, manganese or copper.

The art is replete with well-known TWC compositions. In a typical composition of the present invention, the amount of platinum group metal present will be from about 5 to 150, preferably from about 20 to 80 g/ft³. Of that amount, platinum will typically comprise from about 4 to 125 g/ft³, preferably from about 17 to 67 g/ft³.

A typical method of manufacturing a catalyst composition in accordance with the present invention is to provide the NO_x abatement catalyst as a first coating or layer on the walls of the gas flow passages of a suitable refractory carrier member such as a cordierite honeycomb carrier. This may be accomplished, as is well-known in the art, by impregnating fine particulate activated alumina with one or more catalytic metal components such as platinum or platinum and rhodium, drying and calcining the impregnated activated alumina particles and forming an aqueous slurry of these particles together with particles of bulk ceria. (As used herein, the term "activated alumina" has its usual meaning in the art of a relatively high surface area alumina, as compared, e.g., to α -alumina (α), comprising predominantly γ -alumina (γ) although other phases such as η -alumina (η) may also be present.) The activated alumina may have initially been thermally stabilized, as is well-known in the art, by impregnating it with, for example, a solution of a soluble salt of barium, lanthanum, rare earth metal or other known stabilizer precursor, and calcining the impregnated activated alumina to form a stabilizing metal oxide dispersed onto the alumina. Base metal catalysts may also have been impregnated into the activated alumina, for example, by impregnating a solution of nickel nitrate into the alumina particles and calcining to provide nickel oxide dispersed in the alumina particles.

The carrier member may then be immersed into the slurry of impregnated activated alumina and excess slurry

WO 97/02886

PCT/US96/03491

-17-

removed to provide a thin coating of the slurry on the walls of the gas flow passages of the carrier. The coated carrier is then dried and calcined to provide an adherent coating of the NO_x abatement catalyst to the walls of the passages thereof. The carrier may then be immersed into a slurry of fine particles of a basic oxygenated metal compound, for example, in an aqueous slurry of fine particles of bulk strontium oxide, and a second or overlayer coating of a NO_x sorbent material is thus deposited over the first or underlayer of NO_x abatement catalyst. The member is then dried and calcined to provide a finished catalyst composition in accordance with one embodiment of the present invention.

Alternatively, the alumina particles impregnated with the catalytic component may be mixed with bulk or supported particles of the NO_x sorbent material in an aqueous slurry, and this mixed slurry of NO_x abatement catalyst particles and NO_x sorbent material particles may be applied as a coating to the walls of the gas flow passages of the carrier member.

In another embodiment of the present invention, the refractory carrier member may comprise a body of beads, pellets or particles (collectively referred to as "carrier beads") made of a suitable refractory material such as γ -alumina, coated with the NO_x abatement catalyst and the NO_x sorbent material. A body of such carrier beads may be contained within a suitable perforated container which permits the passage of the exhaust gas therethrough. Figure 1C shows such an embodiment of the invention in which the carrier member 10' comprises a perforated metal container 11 enclosed on all sides by walls 22 within which is formed a regular pattern of perforations 22a. The interior of the container 11 is packed with a plurality of carrier beads 24 on which are disposed the NO_x abatement catalyst and NO_x sorbent material. The member 10' illustrated in Figure 1C would be, as well-known to those skilled in the art, contained within a structure (not shown) designed to direct the flow of the gas stream being

treated through member 10', as indicated in Figure 1C by the unnumbered arrows. In one embodiment of the invention, a proportion, e.g., approximately one-half, of the carrier beads 24 may have the NO_x abatement catalyst
5 coated thereon and the remainder may have the NO_x sorbent material coated thereon. The two different increments of carrier beads 24 are thoroughly admixed so that the NO_x abatement catalyst and NO_x sorbent material are more or less uniformly distributed throughout the interior of the
10 container 11. In another embodiment, the same increment of carrier beads may be coated with both the NO_x abatement catalyst and the NO_x sorbent material, preferably in discrete respective layers thereof, and most preferably with the layer of NO_x sorbent material superposed over the
15 layer of NO_x abatement catalyst.

Without wishing to be bound by any particular theory of operation, it is believed that when the gas stream, e.g., engine exhaust, to be treated is lean, NO_x contained in the gas stream is sorbed onto the NO_x sorbent material,
20 thereby removing the sorbed NO_x from the stream discharged to the atmosphere. The platinum catalytic component is believed to promote such sorption. This lean sorption occurs during a lean operating period which is terminated by rendering the gas stream rich, as may be accomplished
25 by decreasing the air-to-fuel ratio of the combustible mixture fed to the engine generating the exhaust, or by directly introducing a suitable reductant such as hydrocarbons into the exhaust gas stream. The hydrocarbons or other suitable reductant in the gas stream will displace
30 the sorbed NO_x from the NO_x sorbent material, and the displaced NO_x contacts the NO_x abatement catalyst in the presence of the reductant and otherwise under conditions (a suitable elevated temperature) such that the NO_x is reduced. Some or all of the NO_x may be reduced to nitrogen
35 or to nitrogen and N₂O.

In accordance with the method aspect of the present invention, the exhaust gas is alternately adjusted between lean and stoichiometric/rich operating conditions so as to

provide alternating lean operating periods and stoichiometric/rich operating periods. It will be understood that the gas stream, e.g., exhaust, being treated may be selectively rendered lean or stoichiometric/rich either by adjusting the air-to-fuel ratio fed to the engine generating the exhaust or by periodically injecting a reductant into the gas stream upstream of the catalyst. For example, the composition of the present invention is well-suited to treat the exhaust of diesel engines which continuously run lean. In such case, in order to establish a stoichiometric/rich operating period, a suitable reductant, such as diesel fuel, may be sprayed into the exhaust immediately upstream of the catalyst composition of the present invention. Such diesel fuel introduction will be carried out periodically so as to alternate lean and stoichiometric/rich periods of the exhaust. Even if the overall condition of the exhaust (or other gas stream) being treated is lean, stoichiometric/rich local conditions may be periodically imposed at and within the catalyst composition.

During the lean operating periods NO_x is sorbed by the NO_x sorbent material and such sorption may take place at temperatures of from about 150°C to about 600°C . The sorbed NO_x is desorbed during stoichiometric/rich operating periods and/or high temperature periods. The reduction of NO_x during the stoichiometric/rich operating period is promoted by contact of the reactants with the NO_x abatement catalyst under NO_x abatement conditions, typically at temperatures of from about 200°C to about 800°C . For gasoline, a stoichiometric air-to-fuel weight ratio ("A/F") is 14.6. Lambda (λ) is usually used to symbolize the ratio of the actual A/F to the stoichiometric A/F. Therefore, $\lambda = 1$ is a stoichiometric A/F, $\lambda > 1$ is lean and $\lambda < 1$ is rich. Gasoline-fueled engine lean operation is usually at $\lambda =$ about 1.03 to 1.30.

The following examples illustrate the preparation and testing of specific embodiments of the invention. It will be noted that the platinum group metal catalytic compo-

nents are segregated from the NO_x sorbent materials, in accordance with the teachings of the present invention. The following test procedure was employed.

5 Test Procedure A

Catalysts were tested as follows. A feed stream comprising 250 ppm NO, 333 ppm propylene (equivalent to 1000 ppm C₁), 10% steam, 10% O₂, 50 ppm SO₂ and balance nitrogen, giving a C₁ to NO_x ratio of 4 to 1, was flowed
10 through the catalyst, which had previously been heated in air to 100°C, at a space velocity of 25,000/h. The temperature was then ramped up at a rate of 10°C/minute up to a temperature of 600°C and the exit gases were tested for NO_x content. In the Figures showing plots of NO_x removal
15 versus temperature, the amount of NO_x removal is the net of (1) NO_x converted to innocuous gases (N₂ and N₂O) and sorbed by the NO_x sorbent material, less (2) NO_x desorbed from the NO_x sorbent material. The amount of NO_x removal is expressed as a percentage of the total NO_x present in
20 the inlet gas. A negative percentage indicates a net release of NO_x from the sorbent material into the gas stream.

Example 1

25 A. Eleven grams of a soluble platinum salt containing 18.2% Pt by weight was dissolved in 55 ml of deionized water. The resulting platinum salt solution was used to impregnate 100 g of γ-alumina having a BET (Brunnauer-Emmett-Teller) surface area of 150 square meters per gram
30 (m²/g). The platinum salt solution was added with continuous mixing to give an impregnated alumina containing 2% by weight Pt (dry basis). The sample was ball milled about 30 minutes following which five grams of acetic acid was added into the mix to fix the Pt onto the alumina sur-
35 face. The mixture was then slurried with deionized water to make a slurry of 45% solids and the slurry was further milled in a ball mill to a particle size of 90% of the particles being less than 10 microns in diameter. The re-

-21-

sulting slip is designated Slip A.

B. Slip A was coated onto a cylindrical cordierite carrier member measuring 1.5 inches in diameter by 3.0 inches in length and containing 400 cells per square inch ("cps")⁵. The coated carrier member was then dried at 100°C and calcined at 550°C for two hours to give a washcoat weight of the calcined catalyst of 2 g/in³ and a Pt loading of 70 g/ft³. The resulting catalyst member provided a comparative platinum-containing abatement catalyst and was designated Catalyst C-1.¹⁰

Example 2

A. A 250 g quantity of the same type of alumina as used in Part A of Example 1 was thoroughly mixed with 750 g of strontium oxide (SrO) powder, i.e., bulk SrO. The SrO-Al₂O₃ mixture was slowly added to 2000 g of deionized water with mixing. The mixture was kept in an ice bath to prevent the added deionized water from boiling, and mixing was continued to bring the SrO-Al₂O₃ mixture to room temperature. Then 150 g of acetic acid (5% based on slurry weight) was added to the mixture followed by 150 g of Nyacol Al-20 alumina binder (5.1% based on dry solids weight). Mixing was continued for an additional 15 minutes. The resulting slurry was placed in a ball mill jar and ball milled overnight to a particle size of 90% of particles less than 10 micron. The solids level was adjusted with deionized water to 36% solids. The resulting sorbent material (or trap) slurry is designated Slip T-1.²⁵

B. The catalyst member C-1 of Example 1 was coated with Slip T-1 obtained in Part A of this Example 2. The coated member was then dried at 100°C and calcined at 550°C for 2 hours to provide a washcoat overlayer of 1 g/in³ superposed over the Pt/Al₂O₃ layer (now an underlayer) of Catalyst C-1. The resulting composition provided an embodiment of the present invention comprising a bulk strontium oxide sorption material overlayer superposed over a platinum-containing abatement catalyst underlayer and was designated Catalyst E-1.³⁰
³⁵

C. A conventional, commercially available three-way catalyst has a precious metal loading of 70 g/ft³ comprised of Pt and Rh in a weight ratio of 5 to 1 Pt:Rh. The catalytic precious metals are dispersed on activated alumina and the catalyst has a washcoat loading (alumina plus Pt and Rh) of 2 g/in³. The catalyst had been dried and calcined at 450°C. The slurry T-1 obtained in Part A of this Example 2 was coated over the TWC catalyst to provide, after drying at 100°C and calcining at 550°C for 2 hours, an sorbent material overlayer washcoat of 1 g/in³ superposed over the Pt/Rh/Al₂O₃ underlayer. The resulting composition provided an embodiment of the present invention comprising a bulk strontium oxide sorbent material overlayer superposed on an underlayer comprising a platinum and rhodium-containing TWC catalyst, and was designated Catalyst E-2.

D. The results of testing Catalysts C-1, E-1, and E-2 under Test Procedure A are compared in Figure 2, which shows that comparative Catalyst C-1 does not show any NO_x sorption and shows some NO_x conversion with a maximum NO_x reduction at a temperature of about 200°C of the gas stream at the inlet to the test catalyst. (All the temperatures shown in Figures 2-12 (including Figure 2A) are temperatures of the test gas stream at the inlet to the catalyst member being tested. Reference in this and the following examples to the temperatures at which the events of NO_x sorption and release occur are to such gas stream inlet temperatures, sometimes referred to simply as "inlet temperature(s)").) In contrast to the very poor performance of comparative Catalyst C-1, Catalyst E-1 and Catalyst E-2 comprising embodiments of the present invention showed reduction of NO_x at an inlet temperature of about 200°C with 20% NO_x sorption at inlet temperatures between 100 and 150°C, as well as high sorption efficiency in the inlet temperature range of 250 to 400°C. The maximum NO_x sorption was about 60% at an inlet temperature of 300°C. At inlet temperatures greater than 400°C, NO_x was released as indicated by the negative NO_x peak between 400 and

WO 97/02886

PCT/US96/03491

-23-

550°C. Comparison of Catalyst C-1 (Pt/Al₂O₃) with Catalyst E-1 (SrO coated over Pt/Al₂O₃) and E-2 (SrO coated over a TWC catalyst) clearly shows the increase in NO_x sorption capacity of the SrO coated Catalysts E-1 and E-2 as compared to the comparative Catalyst C-1.

E. Catalyst E-1 was tested in accordance with Test Procedure B which comprises cycling the composition of the feed in a laboratory reactor between (1) rich and (2) lean. The test gas contained 250 ppm NO, 333 ppm C₃H₆ (1000 ppm C1), 50 ppm SO₂, and 2% steam and was flowed through the catalysts at a space velocity of 25,000/hr while varying the oxygen concentration in the feed from zero (rich conditions) to 10% (lean conditions). The test was performed on a cylindrical cordierite carrier member having 400 cpsi measuring 3/4 inch in diameter and 1 inch in length but otherwise identical to Catalyst E-1 and so this Example is also designated Catalyst E-1. The cycle was repeated for two cycles at inlet temperatures of 370 - 390°C and one cycle at inlet temperatures of 470 - 500°C. The results are presented in Figure 2A which shows that at lean conditions and at catalyst inlet temperatures of 370 - 390°C and 470 - 500°C, the NO_x was sorbed during the lean cycles. After about 10 minutes, the conditions were changed from lean to rich by replacing the O₂ flow with N₂ and keeping the space velocity fixed. The moment the feed turned rich, a portion of the sorbed NO_x was released as NO_x and a significant amount was reduced to innocuous gases.

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Example 3

The quantity of 204 g of Sr(NO₃)₂ was dissolved in 226 ml of deionized water and the resulting solution was added to 500 g of γ-alumina powder. The thus-impregnated powder was dried at 100°C and calcined at 550°C for 2 hours and allowed to cool. The quantity of 200 g of the SrO impregnated alumina was slurried in 226 ml of deionized water with 10 g of acetic acid and the mixture was ball milled to a particle size of 90% less than 10 mi-

crons. The resulting $\text{SrO}/\text{Al}_2\text{O}_3$ slurry was coated onto a sample of Catalyst C-1 of Example 1. The coated catalyst was then dried at 100°C and calcined at 550°C for 2 hours to provide an overlayer of 1 g/in^3 . The resulting composition provided an embodiment of the present invention comprising a dispersed (not bulk) SrO sorption material overlayer superposed on an underlayer of Catalyst C-1 and was designated Catalyst E-3.

Catalyst E-3 was tested in accordance with Test Procedure A and the results are given in Figure 3, which shows that NO_x removal was attained with a peak at an inlet temperature of about 240°C and a release of desorbed NO_x at an inlet temperature of about 420°C .

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Example 4

The quantity 198 g of $\text{Sr}(\text{OH})_2$ was mixed with 25 g of the same type of alumina as used in Example 1 as a binder and then slurried with 100 ml of deionized water and ball milled to a particle size of 90% of the particles having a diameter of less than 10 microns. The slurry was then coated onto a sample of Catalyst C-1 of Example 1. The $\text{Sr}(\text{OH})_3$ and Al_2O_3 slurry was coated over the $\text{Pt}/\text{Al}_2\text{O}_3$ underlayer of Catalyst C-1. The sample was then dried at 100°C and calcined at 550°C for 2 hours to provide an overlayer of 0.7 g/in^3 . The resulting catalyst provided an embodiment of the present invention comprising a bulk strontium hydroxide sorption material layer superposed on a platinum-containing abatement catalyst, and was designated Catalyst E-4.

Catalyst E-4 was tested according to Test Procedure A and the results are given in Figure 4. It is clear from the results, which show a removal peak for NO_x at an inlet temperature of about 280°C that the provision of an overlayer $\text{Sr}(\text{OH})_2$ on the $\text{Pt}/\text{Al}_2\text{O}_3$ underlayer results in a high NO_x sorption and reduction capacity.

Example 5

Two hundred grams of a slurry of 35% solids of SrO powder in deionized water was mixed with 70 g of CeO₂ powder and deionized water was added to make a 40% solids slurry. The resulting mixture was added to 300 ml of deionized water and ball milled for 24 hours to provide a particle size of 90% of the particles being less than 10 microns in diameter. This slurry was coated over a sample of Catalyst C-1 of Example 1. The coated catalyst was then dried at 100°C and calcined at 550°C for 2 hours to provide an overlayer washcoat loading of 1.3 g/in³ superposed over the Pt/Al₂O₃ underlayer of Catalyst C-1. The resulting composition provided an embodiment of the present invention comprising an sorbent material overlayer of a mixture of strontium oxide and bulk ceria superposed on a platinum-containing abatement catalyst and was designated Catalyst E-5.

Catalyst E-5 was tested using the same gas feed and flow as in Test Procedure A except that the propylene was not included, i.e., no hydrocarbon was included in the feed. The results are given in Figure 5. It is clear from the results that this material showed excellent NO_x removal, peaking at inlet temperatures of about 180°C and 400°C. NO_x desorption starts at an inlet temperature of about 480°C.

Example 6 (Comparative)

A soluble platinum salt was added to a ball mill containing Slip T-1 from Part A of Example 2 (Slip T-1 contains 75 weight % SrO and 25 weight % Al₂O₃) to give 2% by weight Pt dispersed on Slip T-1. This provided 70g/ft³ Pt in the finished catalyst. The sample was ball milled about thirty minutes, 5% by weight (based on the weight of the slurry) acetic acid was added and the slip was further ball milled to a particle size of 90% of the particles having a diameter of less than 10 microns. The resulting slip was coated onto 400 cpsi cordierite carrier members measuring 0.75 inches in length and 1.0 inches in diame-

ter, dried and calcined at 550°C for 2 hours to give 2 g/in³ of washcoat loading. The resulting comparative sample provided a platinum catalytic component dispersed onto the bulk strontium oxide sorbent material, i.e., the platinum group metal catalytic component was not segregated from the sorbent material. The resulting comparative catalyst was designated Catalyst C-2.

Catalyst testing results using Test Procedure A on comparative Catalyst C-2 and Catalyst E-1 of the present invention are shown in Figure 6. It is clear from these results that impregnation of Pt on bulk SrO (as suggested by the Takahashi et al and SAE papers described above) does not give the superior NO_x trapping and reduction performance which is obtained with Catalyst E-1. In fact, less than 10% NO_x removal is observed over Catalyst C-2 at inlet temperatures of from about 150 - 600°C, indicating that mixing of the catalytic and trapping functions by supporting the platinum catalytic metal component on the strontium oxide sorption material results in very poor efficiency for NO_x removal.

Example 7 (Comparative)

Activated alumina having a BET surface area of about 150 g/m² was impregnated with an aqueous solution of strontium nitrate. The impregnated powder sample was dried at 120°C overnight and then calcined by heating from ambient temperature to 600°C over a two-hour period and then held at 600°C for an additional four hours to provide alumina containing 20% by weight (calcined basis) SrO. An aqueous slip of 35% solids was made from the resulting NO_x sorbent material powder by adding the powder to deionized water to which sufficient platinum was added using an aqueous solution of a soluble platinum salt to provide 2% by weight Pt in the calcined product. Samples were prepared by coating 400 cpsi cordierite carrier members to give 2 g/in³ of washcoat loading after calcination at 550°C for 2 hours (i.e., 70 g/ft³ Pt). The resulting comparative catalyst had the platinum catalytic metal compo-

ment impregnated onto the same (alumina) support particles onto which the dispersed strontium oxide (via calcination of strontium nitrate) sorbent material was dispersed.

Thus, the catalytic metal component, in this case a platinum catalytic metal component, was not segregated from the NO_x sorbent material as required by the present invention. This comparative catalyst was designated Catalyst C-3.

Catalyst testing results using Test Procedure A were carried out on comparative Catalyst C-3, along with Catalyst E-1 of the present invention and the results are shown in Figure 7. Catalyst E-1 is seen to remove NO_x over a broad inlet temperature range of from about 150 - 400°C with NO_x release above this temperature, whereas Catalyst C-3 shows only minor, less than 15%, NO_x removal at an inlet temperature range of from about 150 - 300°C and correspondingly much lower NO_x release at higher temperatures. Thus, as also shown in Example 6, failure to segregate the platinum catalytic metal component and the strontium oxide NO_x sorbent material component in the manner required by the teachings of the present invention, in this case by supporting both species on the same Al_2O_3 particles, results in poor NO_x removal efficiency. As noted elsewhere herein, this is contrary to the teachings of the Takahashi et al and SAE papers noted above.

Example 8

A. Mixed E-1

Seventy-five ml of Slip A of Part A of Example 1 diluted with deionized water to 37.2% solids, and 45.3 ml of Slip T-1 of Part A of Example 2 diluted with deionized water to 30.8% solids were thoroughly mixed together. The resulting slip was used to coat 400 cpsi cordierite carrier members to give 3 g/in³ of washcoat loading after calcination at 550°C for 2 hours to provide a catalyst having 70 g/ft³ Pt. The result is a "mixed" version of Catalyst E-1 in which the NO_x abatement catalyst and the NO_x sorption material are not in discrete layers but are mixed in

a single layer. The resulting sample is designated Catalyst E-1M, the "M" standing for mixed.

B. Reverse E-1

5 Slip T-1 of Part A of Example 2 was coated as an underlayer on 400 cpsi cordierite carrier members to give 1 g/in³ washcoat after calcination at 550°C for 2 hours. These carrier members were then further coated with 2 g/in³ of Slip I as an overlayer containing 70 g/ft³ of
10 platinum and further calcined at 550°C for 2 hours. The result is a version of Catalyst E-1 in which the layers are reversed relative to Catalyst E-1, i.e., the NO_x sorbent material is the underlayer and the NO_x abatement catalyst is the overlayer. The resulting sample is design-
15 nated Catalyst E-1R, the "R" standing for reversed.

Figure 8 shows the results of testing Catalysts E-1, E-1M and E-1R using Test Procedure A. Clearly from these results a layered structure with the NO_x trapping component on the overlayer and the NO_x abatement catalyst on
20 the underlayer is preferred. It must be noted however that adequate NO_x trapping and conversion is observed with the other two materials as well. Nonetheless, it is preferred to have the NO_x sorbent material and the NO_x abatement catalyst disposed in the layered structure exempli-
25 fied by Catalyst E-1, wherein the NO_x abatement catalyst is the underlayer.

Example 9

A comparative material was made containing only the
30 NO_x sorbent material, as follows. Slip T-1 of Part A of Example 2 was coated onto a 400 cpsi cordierite carrier member which was then calcined at 550°C for 2 hours to give a 1 g/in³ washcoat. The resulting comparative was designated Catalyst C-4.

35 In Figure 9, NO_x removal over Catalyst E-1 and comparative Catalyst C-4 is compared using test conditions similar to those used in Test Procedure A except that no reductant is present. Because of the absence of hydrocar-

bons (or other reductant) in the feed gas, the NO_x removals shown in this Figure result from NO_x trapping alone, there being no NO_x conversion, i.e., reduction of NO_x by a reductant. Clearly from these results it is shown that

5 the platinum group metal catalytic component in the underlayer of Catalyst E-1, plays a role in promoting NO_x sorption by the NO_x sorbent material, i.e., strontium oxide in this case. Very little NO_x removal by comparative Catalyst C-4 is observed, i.e., less than 5% above an inlet

10 temperature of 150°C , whereas the data for Catalyst E-1 show two NO_x removal peaks at inlet temperatures of about 150°C and about 360°C , each with over 30% NO_x removal. At higher inlet temperatures, about $400 - 575^\circ\text{C}$, a correspondingly large NO_x desorption peak is shown for Catalyst

15 E-1.

Example 10

A calcined cordierite catalyst core, 400 cpsi, had a washcoat of 2 g/in^3 deposited from Slip A of Part A of Example 1 as an underlayer. An overlayer of 1 g/in^3 was applied using a slip prepared with 150 g Ba_2SrO_6 , 50 g Al_2O_3 , 31 g A-20 Nalco alumina binder (20% solids) and 180 g of deionized water. The resulting layered material was calcined to 550°C for 2 hours. The resulting catalyst is

25 designated Catalyst E-10.

Catalyst E-10 was tested according to Test Procedure A for activity for NO_x reduction and trapping and the test results are given in Figure 10. Clearly this material is active for both NO_x conversion and sorption over a fairly

30 broad inlet temperature range of $100 - 400^\circ\text{C}$ and releases NO_x above an inlet temperature of about 400°C .

Example 11

Lean/Rich Testing

35 Catalysts E-1 and E-10 were tested in an alternating rich/lean environment under the following conditions at the data point temperatures shown in Figures 11A and 11B. Thus, the data plotted in Figure 11A were developed at

WO 97/02886

-30-

PCT/US96/03491

inlet temperatures ranging from 200°C to 450°C at 50°C intervals and the data plotted in Figure 11B were developed at inlet temperatures of from 150°C to 500°C at 50°C intervals.

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Space Velocity = 25,000/h

The inlet temperature was held steady for one-half hour at each of the temperatures shown in Figures 11A (200 - 450°C, at 50°C intervals) and 11B (150 - 500°C, at 50°C intervals).

10

Composition of Inlet Gas

NO = 250 ppm	H ₂ O = 10%	CO = 1,000 ppm
C ₃ H ₆ = 16.7 ppm	SO ₂ = 50 ppm	H ₂ = 330 ppm
O ₂ = 0.07% (rich modes) <--> 6.0% (lean modes)		

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The frequency of cycling between lean and rich modes was 60 seconds in each mode. Preconditioning of the test catalysts was carried out for about 30 minutes by subjecting the catalysts to the 60-second lean and rich periods at each test temperature. The results obtained for lean/-rich testing of preconditioned Catalysts E-1 and E-10, are plotted in, respectively, Figures 11A and 11B. In these Figures the vertical lengths of the bars represent the range of NO_x sorption observed during the lean pulses. The percentage of NO_x removal at the start of a lean cycle is shown by the top of each vertical bar in Figures 11A and 11B, and the percentage of NO_x removal at the end of each lean cycle is shown by the bottom of each vertical bar. The cyclic way in which the test was run ensures that during rich operating periods the catalyst was cleaned of stored NO_x so that NO_x sorption could occur again in the next lean operating period. Clearly, both Catalyst E-1 and Catalyst E-10 demonstrated the ability to sorb NO_x over a broad temperature range for an extended period of time with alternating periods of rich and lean operation.

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Example 12

A. A catalyst sample was prepared identically to Catalyst C-1 of Part B of Example 1, the sole difference being that the washcoat loading of the calcined catalyst was 1.67 g/in³.

B. An alumina slurry made of activated alumina was ball milled to 90% of the particles being less than 10 microns in diameter using 5% acetic acid in the slurry. The slurry contained 35% solids based on dried weight. The alumina was then coated over the catalyst obtained in Part A of this Example 12. The catalyst was then dried at 100°C and calcined at 550°C for 2 hours to provide 0.6 g/in³ of an alumina washcoat layer in the calcined sample.

C. The calcined catalyst obtained from Part B of this Example 12 was then coated with Slip T-1 from Part A of Example 2. The coated catalyst was then dried and calcined at 550°C for 2 hours to give a NO_x sorbent material overlayer of 0.7 g/in³. The total washcoat loading of the resulting three-layered catalyst was 3 g/in³, having a NO_x abatement catalyst underlayer of platinum dispersed on alumina, an intermediate layer of alumina, and an overlayer of NO_x sorbent material comprised of bulk strontium oxide and bulk alumina. This catalyst was designated Catalyst E-12.

Catalyst E-12 was tested according to Test Procedure A. The results are plotted in Figure 12 and clearly show that even with an intermediate layer separating the NO_x sorbent material overlayer from the NO_x abatement catalyst underlayer, catalyst E-12 demonstrated good efficiency of sorbing and converting NO_x. Note the high NO_x removal at inlet temperatures from about 275°C to 350°C. Sorbed NO_x was released at temperatures greater than 375°C.

WO 97/02886

PCT/US96/03491

-32-

While the invention has been described in detail with respect to specific embodiments thereof, it will be appreciated that numerous variations to the specific embodiments may well occur to those skilled in the art upon a reading and understanding of the foregoing and it is intended to embrace such variations within the scope of the appended claims.

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-33-

THE CLAIMS

What is claimed is:

1. A composition for NO_x abatement in a gas stream, the composition comprising a NO_x abatement catalyst and a NO_x sorbent material disposed in proximity to each other on a common refractory carrier member;

the NO_x abatement catalyst comprising a catalytic metal component comprised of a platinum catalytic metal component, the catalytic metal component being dispersed on a first refractory catalyst support material; and

the NO_x sorbent material comprising at least one basic oxygenated metal compound which is segregated from the catalytic metal component at least to the extent that (a) when the NO_x sorbent material is dispersed on a refractory support material, the catalytic metal component and the NO_x sorbent material are not dispersed on the same increment of refractory support material, and (b) when the NO_x sorbent material is in bulk form, the catalytic metal component is not impregnated into the bulk NO_x sorbent material and providing that when the catalytic material is disposed as a first discrete layer on the carrier member, a second discrete layer of NO_x sorbent material comprises an overlayer superimposed on the catalytic material layer.

2. The composition of claim 1 wherein the NO_x sorbent material is selected from the group consisting of one or more of metal oxides, metal carbonates, metal hydroxides and mixed metal oxides.

3. The composition of claim 1 or claim 2 wherein the NO_x sorbent material further comprises ceria.

AMENDED SHEET

PCT/US 96/03491
IPEA/US 14 OCT '97

-34-

4. The composition of claim 1 or claim 2 wherein the NO_x sorbent material further comprises bulk ceria.

5. The composition of claim 1 or claim 2 wherein the catalytic metal component further comprises at least one other catalytic metal component in addition to the platinum catalytic metal component.

6. The composition of claim 1 or claim 2 wherein the catalytic metal component further comprises at least one other platinum group metal catalytic component in addition to the platinum catalytic metal component.

7. The composition of claim 1 wherein the NO_x sorbent material comprises a mixed metal oxide selected from the group consisting of one or more of barium strontium tungstate, barium strontium niobate, strontium titanate, barium zirconate, barium silicate and barium strontium titanate.

8. The composition of claim 1 wherein the NO_x sorbent material is selected from the group consisting of one or more of metal oxides, metal hydroxides, metal carbonates, and mixed metal oxides, wherein the metals of the metal oxides, metal hydroxides and metal carbonates and at least one of the metals of the mixed metal oxides are selected from the group consisting of one or more of lithium, sodium, potassium, rubidium, cesium, magnesium, calcium, strontium and barium.

9. The composition of claim 1 wherein the refractory support material comprises a refractory metal

PCT/US 96/03491
IPEA/US 14 OCT '97

-35-

oxide, and the NO_x sorbent material is selected from the group consisting of one or more of oxides and hydroxides of one or more of magnesium, calcium, strontium and barium.

10. The composition of claim 1 or claim 2 wherein the NO_x abatement catalyst is admixed with the NO_x sorbent material.

11. The composition of claim 1 or claim 2 wherein the NO_x abatement catalyst is disposed as a first discrete layer on the refractory carrier member and the NO_x sorbent material is disposed as a second discrete layer on the refractory carrier member.

12. The composition of claim 11 wherein the first discrete layer comprises an underlayer disposed on the carrier member and the second discrete layer comprises an overlayer superposed on the underlayer.

13. The composition of claim 11 wherein the first discrete layer and the second discrete layer are in direct contact one with the other.

14. The composition of claim 11 wherein the first discrete layer and the second discrete layer are separated by an intervening layer of material.

15. The composition of claim 11 wherein the refractory carrier comprises a body having a plurality of gas flow passages extending therethrough, the passages being defined by passage walls, and the first and second layers are disposed on the passage walls.

AMENDED SHEET

PCT/US 96/03491
IPEA/US 14 OCT '97

-36-

16. The composition of claim 11 wherein the refractory carrier comprises a body of carrier beads retained within a gas-permeable container.

17. The composition of claim 16 wherein the first layer is disposed on one increment of carrier beads and the second layer is disposed on a second increment of carrier beads, and the first and second increments of carrier beads are admixed within the container.

18. The composition of claim 16 wherein the first and second layers are disposed on the same increment of carrier beads.

19. The composition of claim 1 wherein the NO_x sorbent material comprises strontium oxide.

20. A composition for NO_x abatement in a gas stream comprising:

a refractory carrier member comprising a body having a plurality of gas flow passages extending there-through, the passages being defined by passage walls;

a NO_x abatement catalyst comprising a catalytic metal component comprised of a platinum catalytic metal component, the catalytic metal component being dispersed on a refractory metal oxide support, the abatement catalyst being disposed on the passage walls as a first discrete layer; and

a NO_x sorbent material comprising a bulk oxide selected from the group consisting of one or more of oxides of magnesium, calcium, strontium and barium, the NO_x sorbent

-37-

material being disposed on the passage walls as a second discrete layer.

21. The composition of claim 20 wherein the NO_x abatement catalyst further comprises at least one other platinum group metal component to the platinum catalytic metal compound.

22. The composition of claim 20 or claim 21 wherein the first discrete layer comprises an underlayer disposed on the carrier member and the second discrete layer comprises an overlayer superposed on the underlayer.

23. The composition of claim 20 wherein the NO_x sorbent material further comprises ceria.

24. The composition of claim 20 or claim 21 wherein the NO_x sorbent material comprises bulk strontium oxide.

25. The composition of claim 20 or claim 21 wherein the NO_x sorbent material comprises bulk strontium hydroxide.

26. A method of NO_x abatement comprising contacting a gas stream containing NO_x with a NO_x abatement composition, the composition comprising a NO_x abatement catalyst and a NO_x sorbent material disposed in proximity to each other on a common refractory carrier member, (i) the NO_x abatement catalyst comprising a catalytic metal component comprised of a platinum catalytic metal component and, optionally, at least one other platinum group metal catalytic component, the catalytic metal component being dispersed on a first refractory metal oxide support, (ii) the NO_x sorbent

PCT/US 96/03491
IPEA/US 14 OCT '97

-38-

material optionally being a bulk material and comprising at least one material selected from the group consisting of basic oxygenated metal compounds and, optionally, further comprising ceria, and (iii) wherein the NO_x sorbent material is segregated from the catalytic metal component, at least to the extent that (a) when the NO_x sorbent material is dispersed on a refractory support material, the catalytic metal component and the NO_x sorbent material are not dispersed on the same increment of refractory support material, and (b) when the NO_x sorbent material comprises a bulk material, the catalytic metal component is not impregnated into the bulk NO_x sorbent material and providing that when the catalytic material is disposed as a first discrete layer on the carrier member, a second discrete layer of NO_x sorbent material comprises an overlayer superimposed on the catalytic material layer;

the method including periodically adjusting the composition of the gas stream between lean and stoichiometric/rich conditions to thereby provide alternating lean operating condition periods and stoichiometric/rich operating condition periods, and maintaining NO_x abatement conditions during the stoichiometric/rich operating condition periods, whereby during the lean operating periods NO_x is sorbed by the NO_x sorption material and during the stoichiometric/rich operating periods the NO_x abatement catalyst promotes the reduction of NO_x.

27. The method of claim 26 wherein the NO_x sorbent material comprises a mixed metal oxide selected from the group consisting of one or more of barium strontium tungstate, barium strontium niobate, strontium titanate

AMENDED SHEET

PCT/US 96/03491

IPEA/US 14 OCT '97

-38-

barium zirconate, barium silicate and barium strontium titanate.

28. The method of claim 26 wherein the NO_x sorbent material is selected from the group consisting of one or more metal oxides, metal carbonates, metal hydroxides and mixed metal oxides, wherein the metals of the metal oxides, metal carbonates, metal hydroxides and at least one of the metals of mixed metal oxides are selected from the group consisting of one or more of lithium, sodium, potassium, rubidium, osmium, magnesium, calcium, strontium and barium.

29. The method of claim 26 wherein the NO_x abatement catalyst further comprises at least one other platinum group metal catalytic component and the NO_x sorbent material is selected from the group consisting of one or more of oxides of magnesium, calcium, strontium and barium.

30. The method of claim 26 wherein the NO_x sorbent material comprises strontium oxide.

31. The method of claim 26 wherein the NO_x abatement catalyst is disposed as a first discrete layer on the refractory carrier member and the NO_x sorbent material is disposed as a second discrete layer on the carrier member.

32. The method of claim 31 wherein the first discrete layer comprises an underlayer disposed on the carrier member and the second discrete layer comprises an overlayer superposed on the underlayer.

FIG. 1

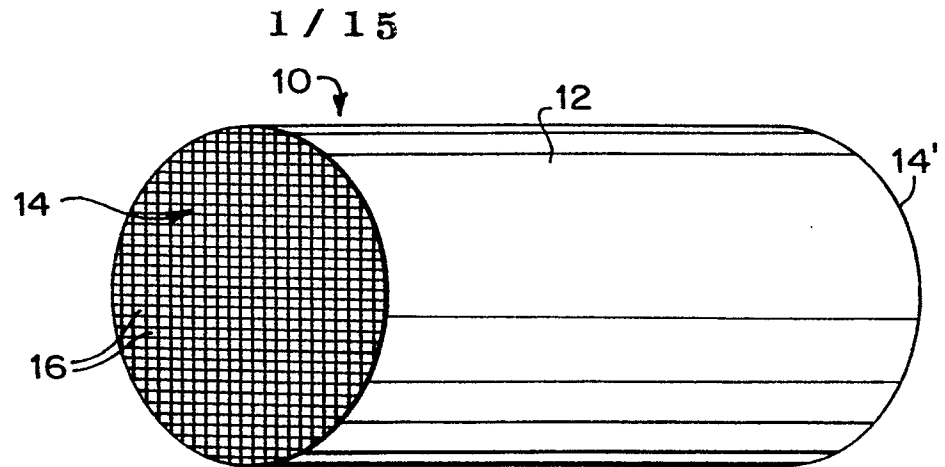


FIG. 1A

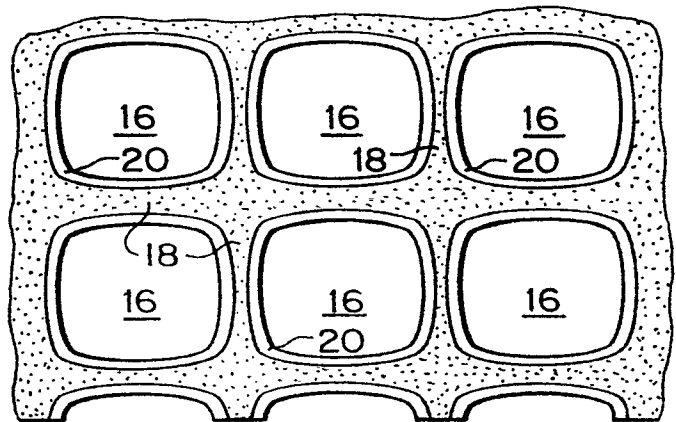
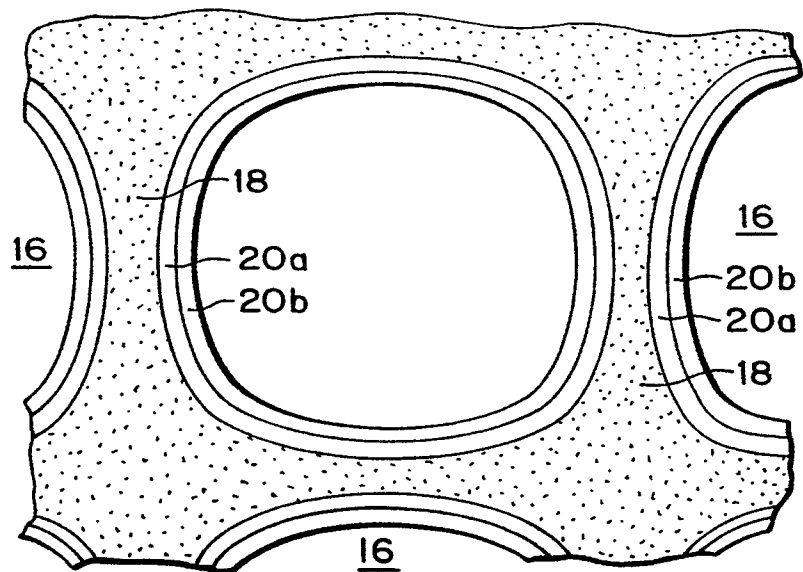


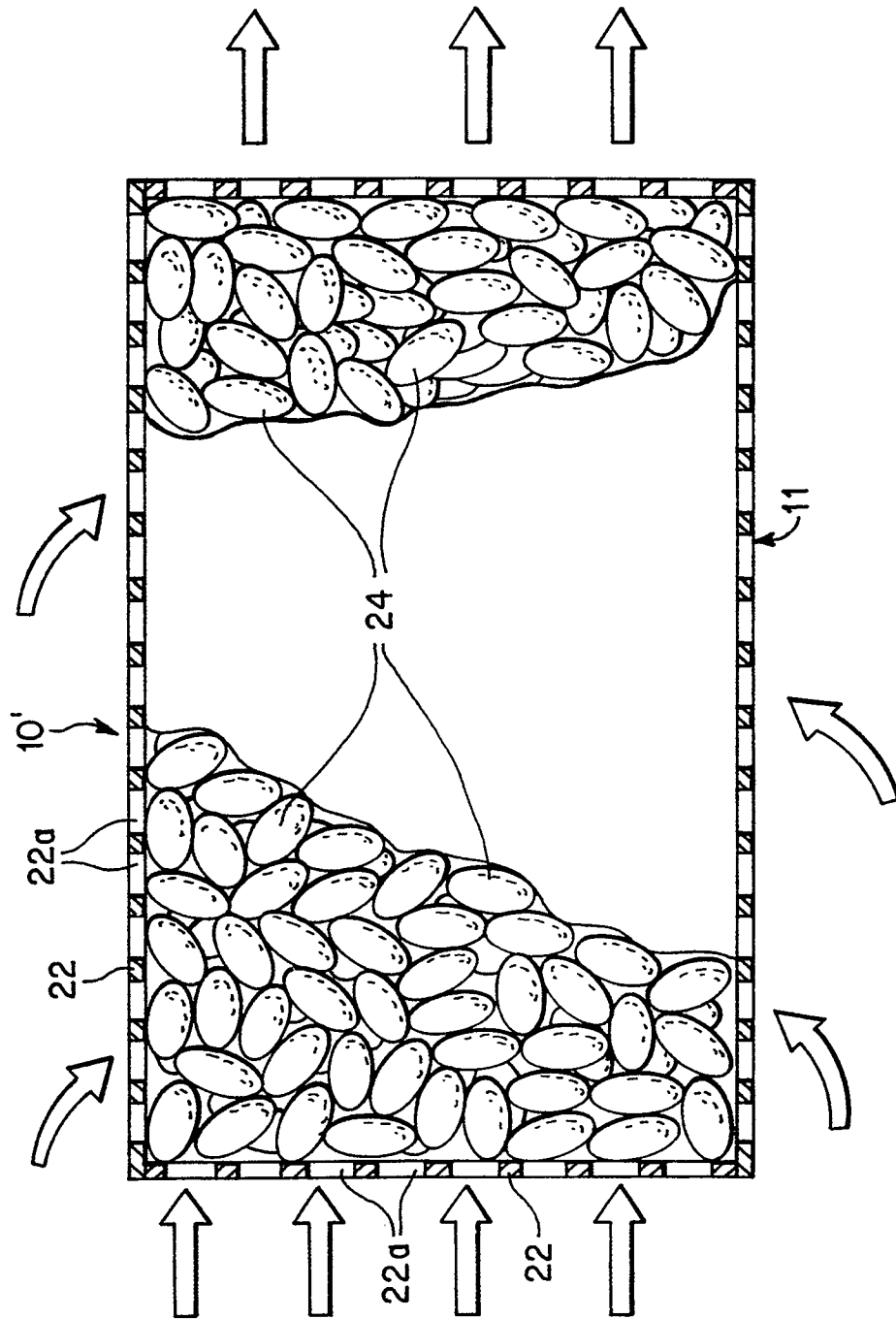
FIG. 1B



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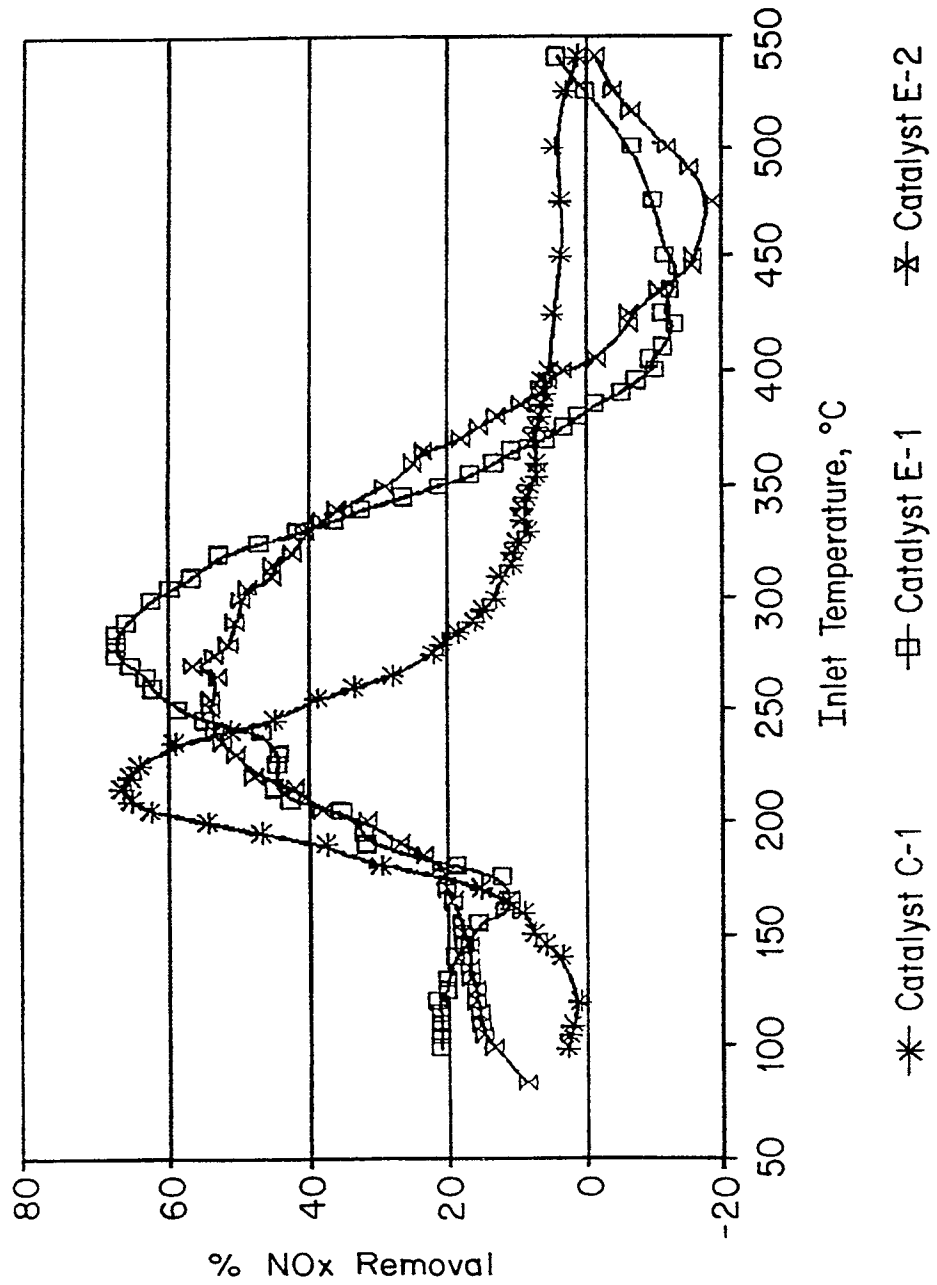
2 / 15

FIG. 1C



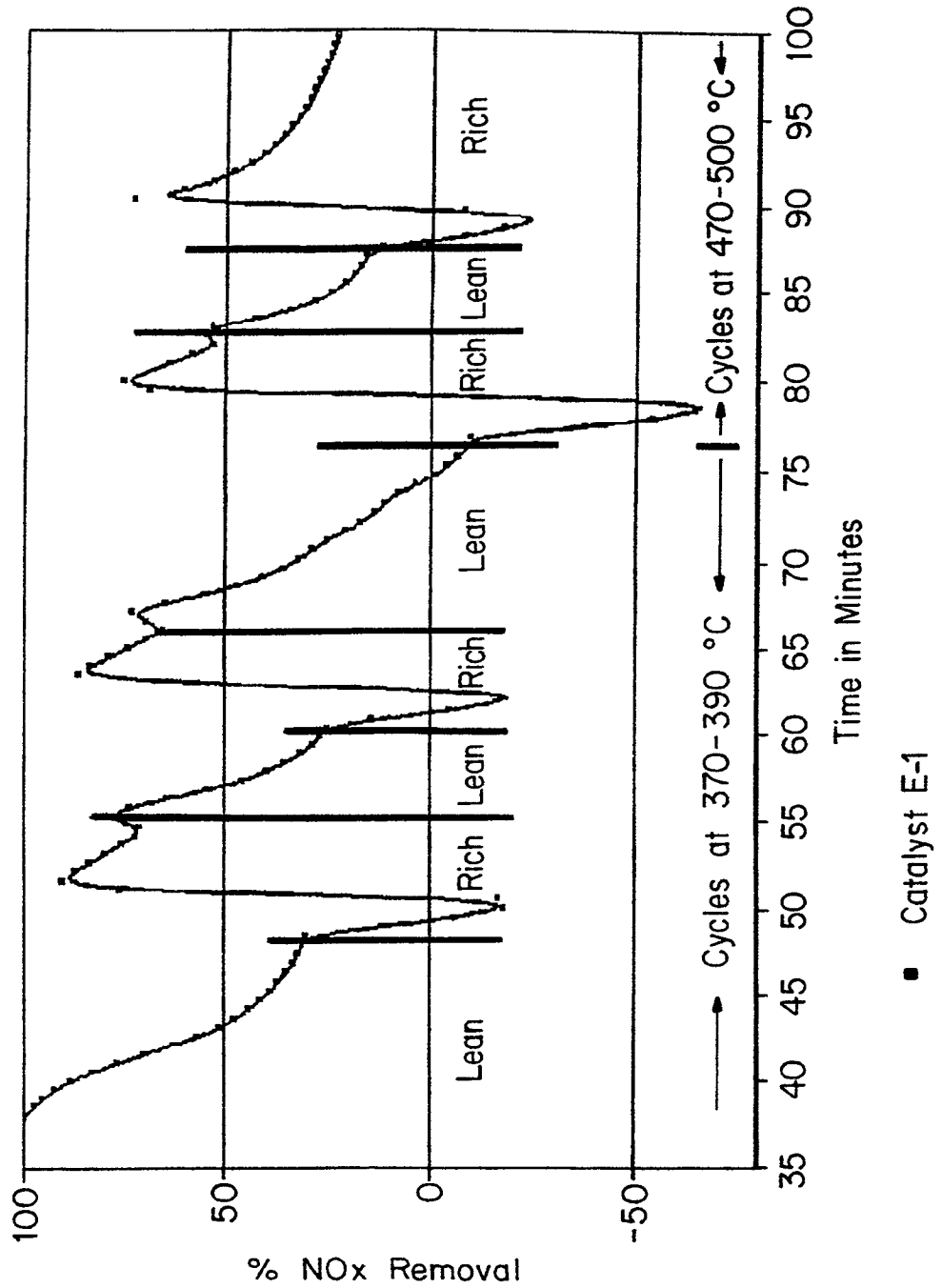
3 / 15

FIG. 2



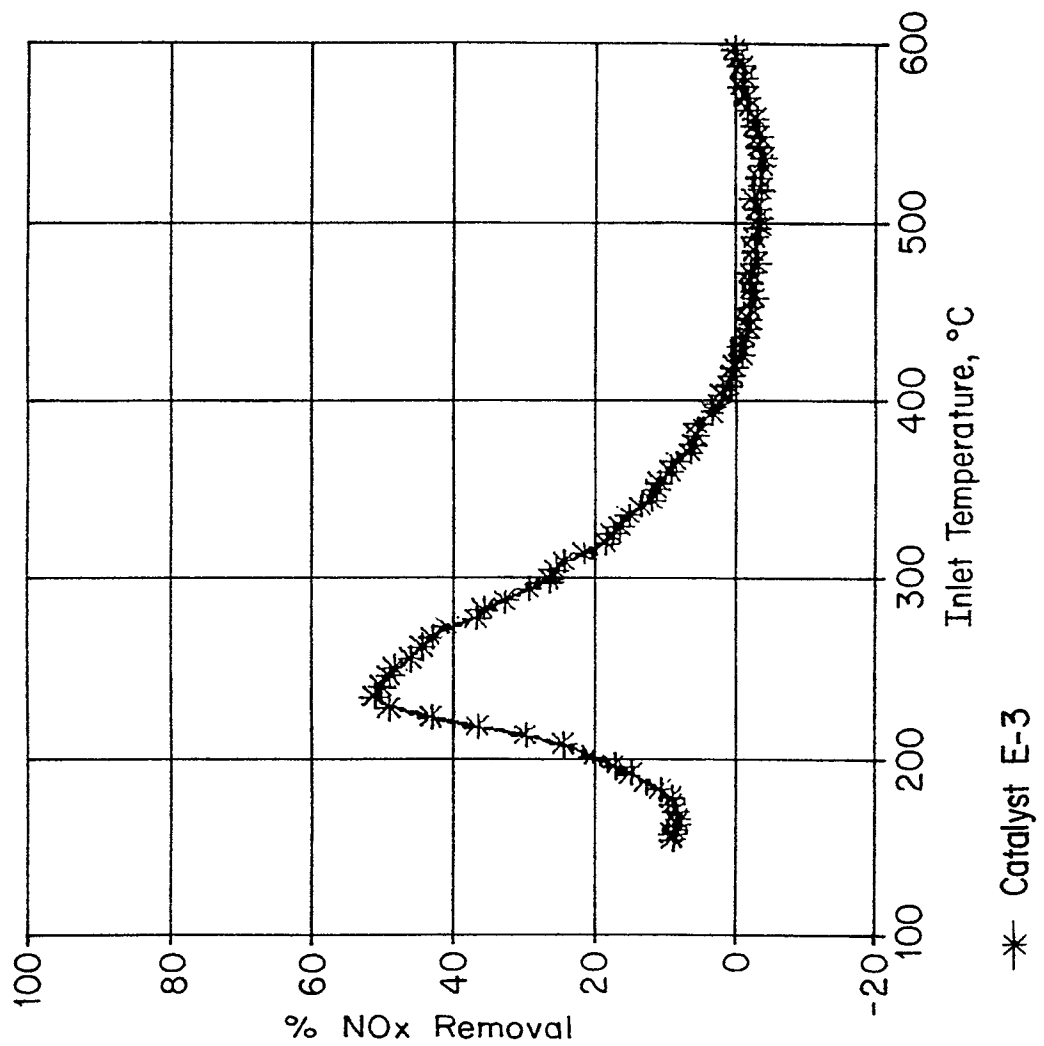
4 / 15

FIG. 2A

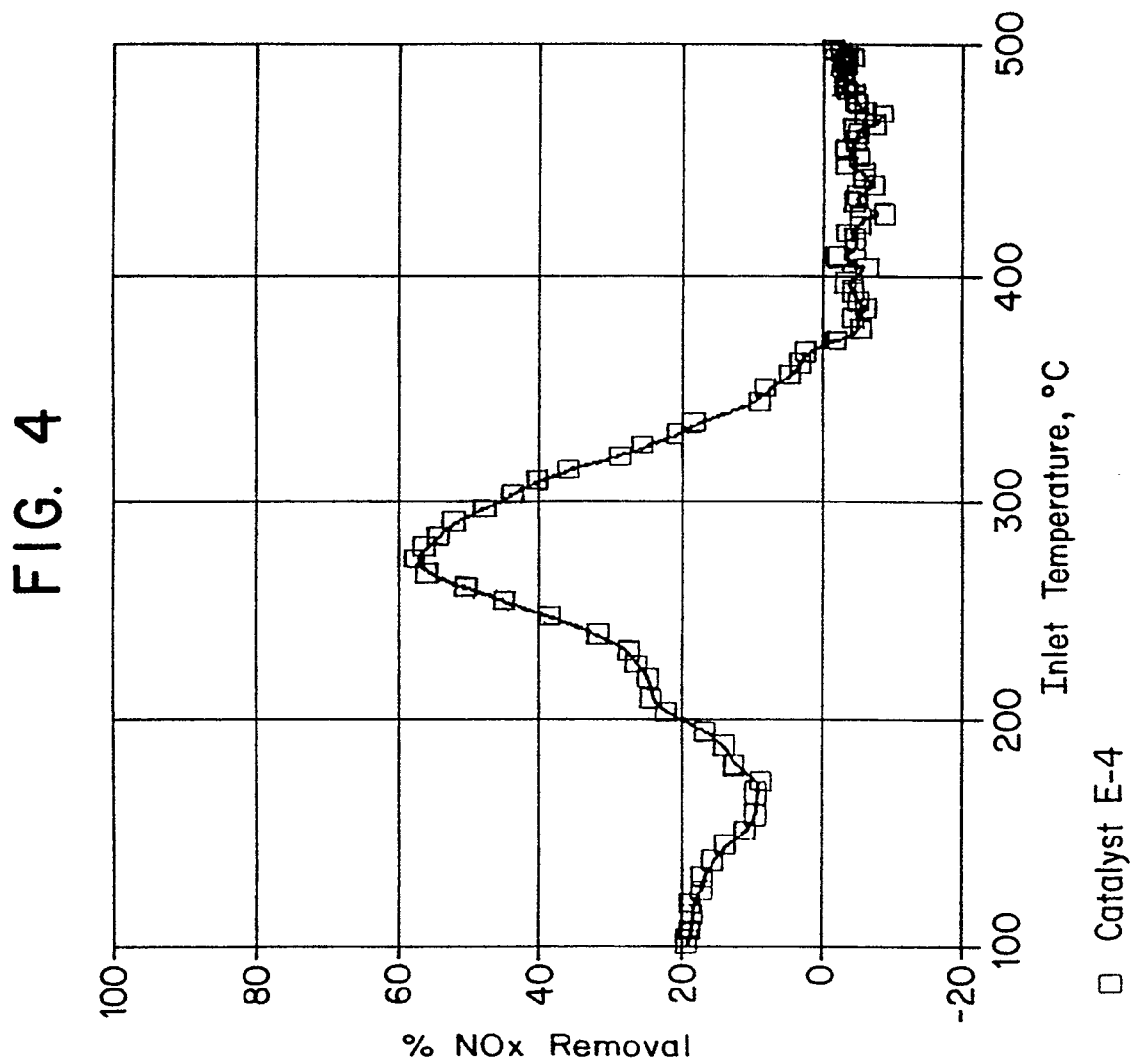


5 / 15

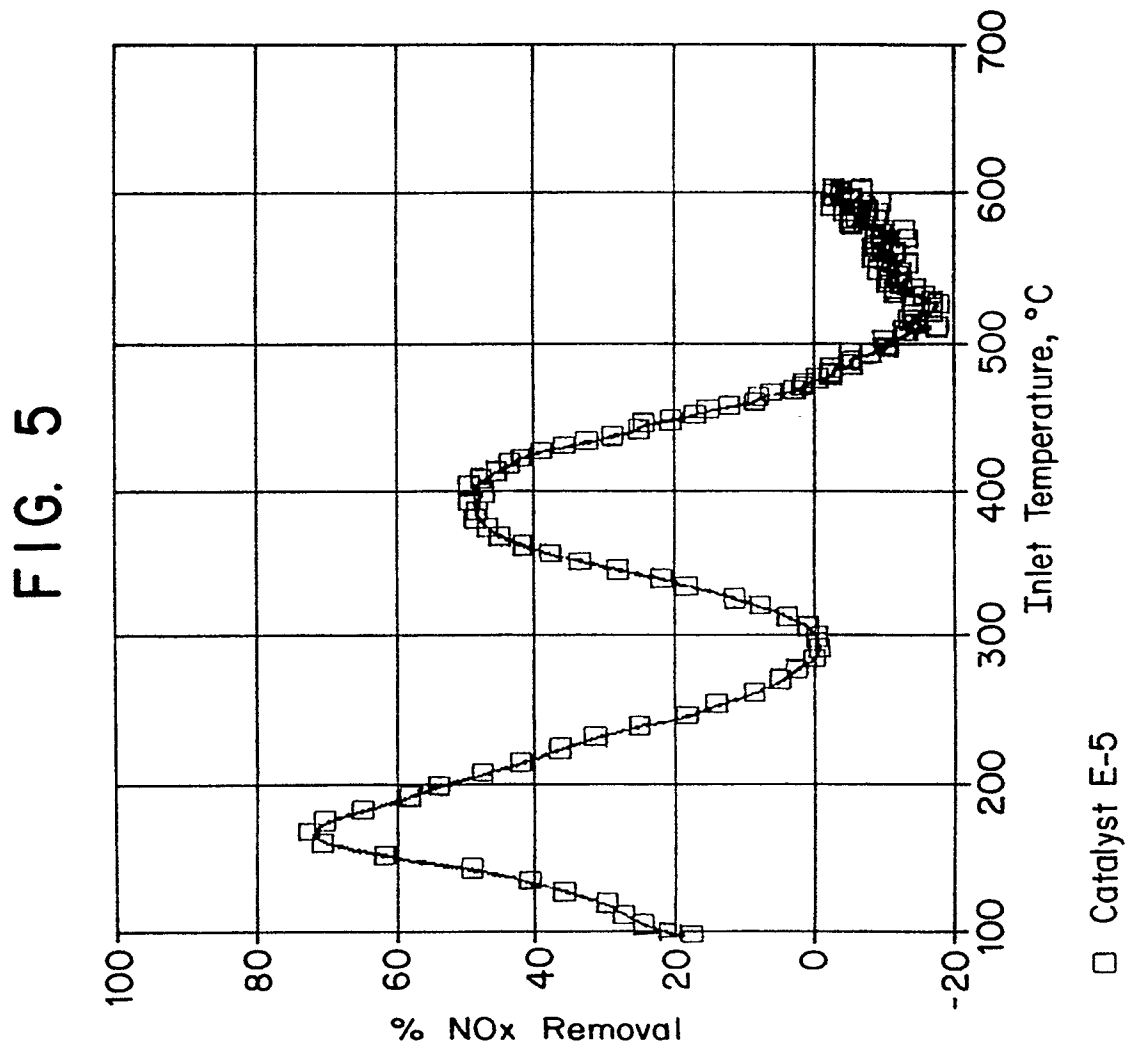
FIG. 3



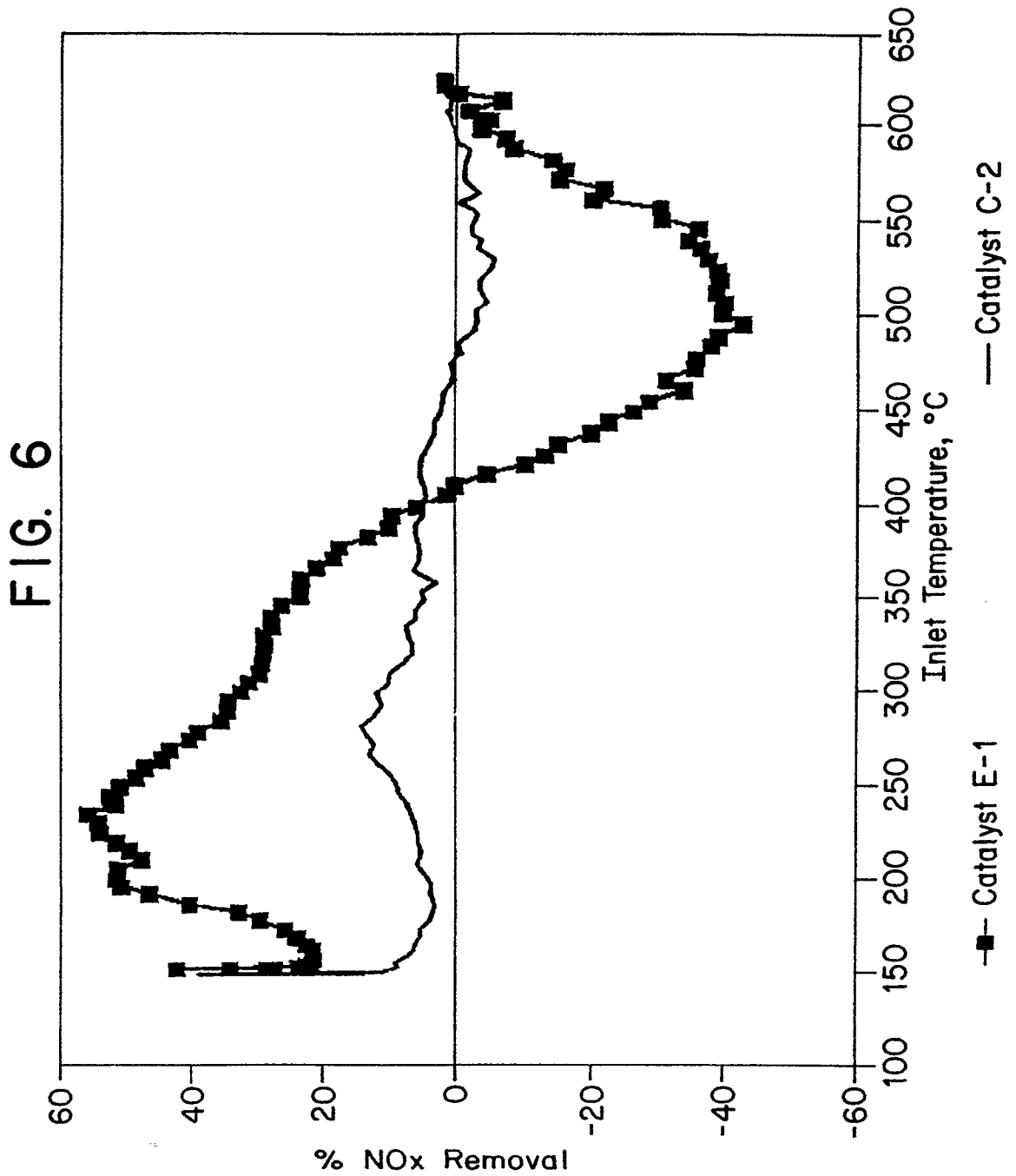
6 / 15



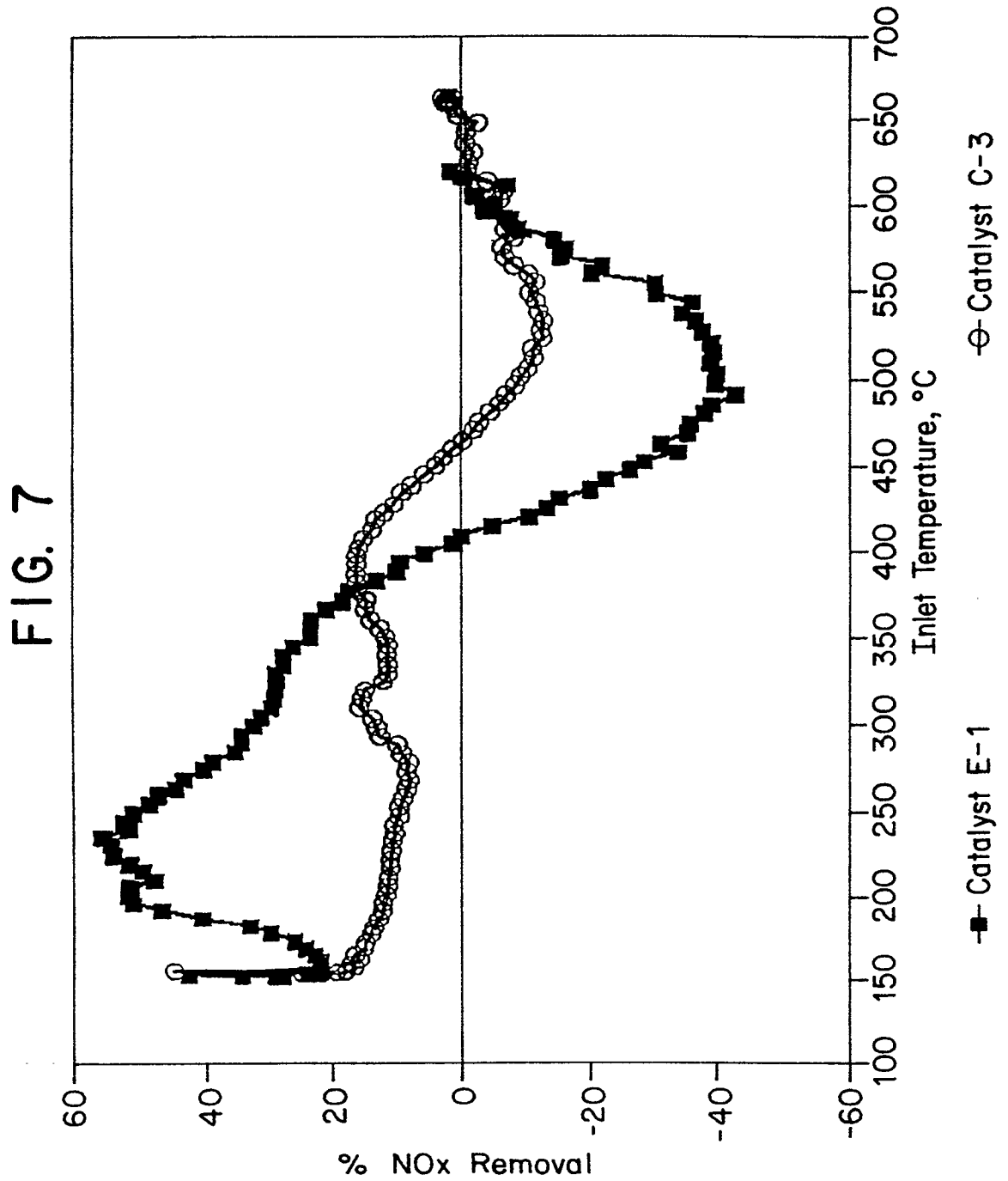
7 / 15



8 / 15

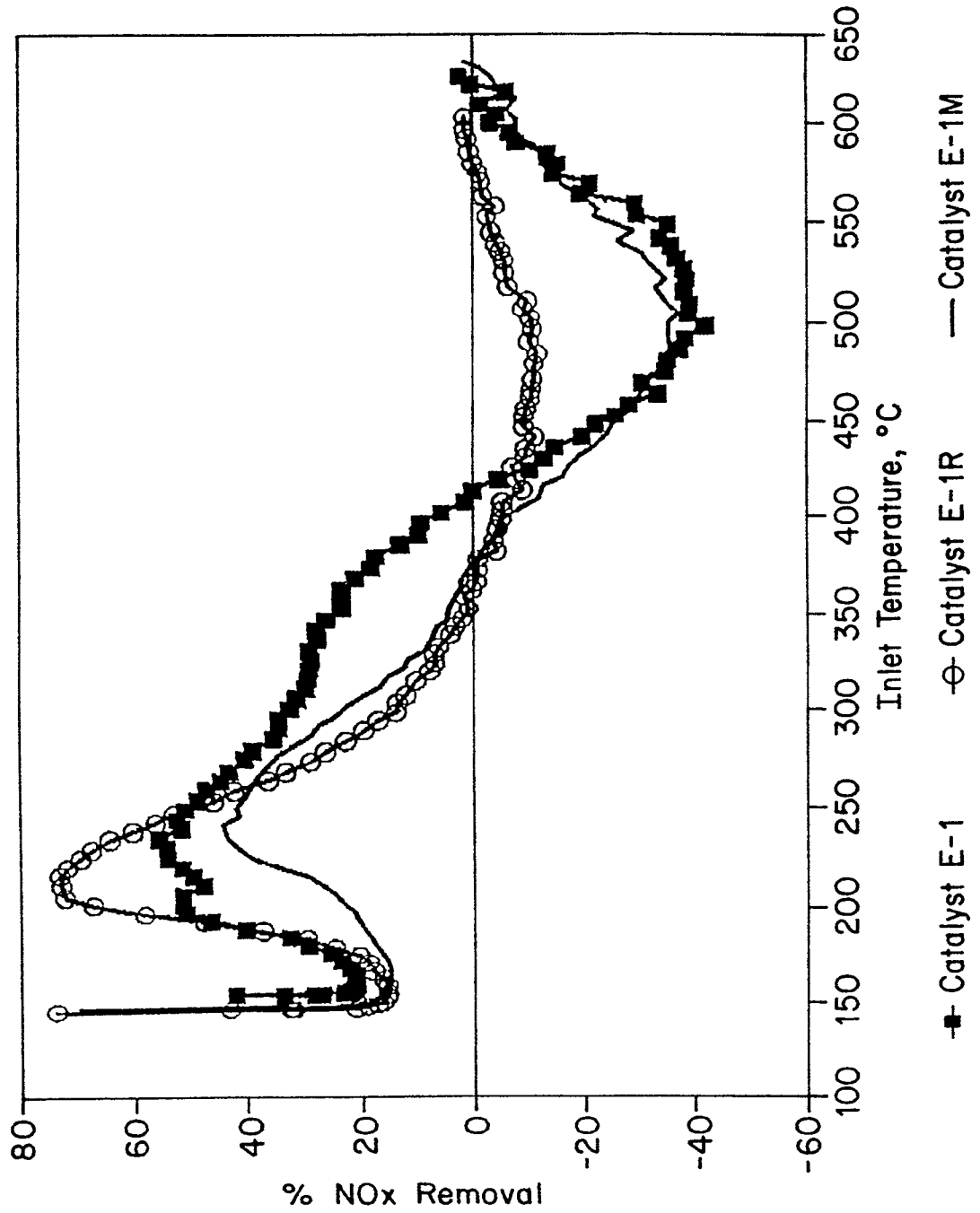


9 / 15

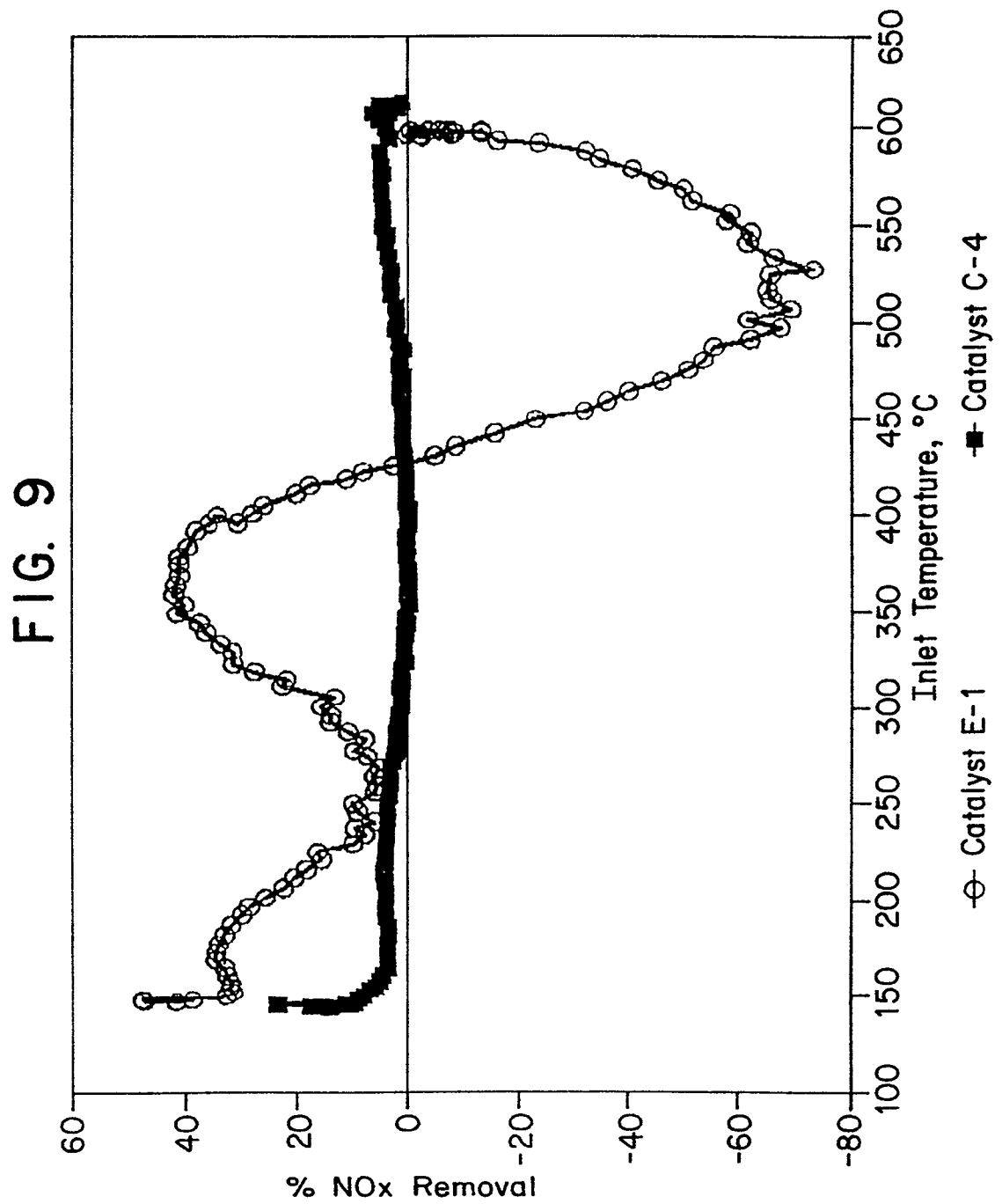


10 / 15

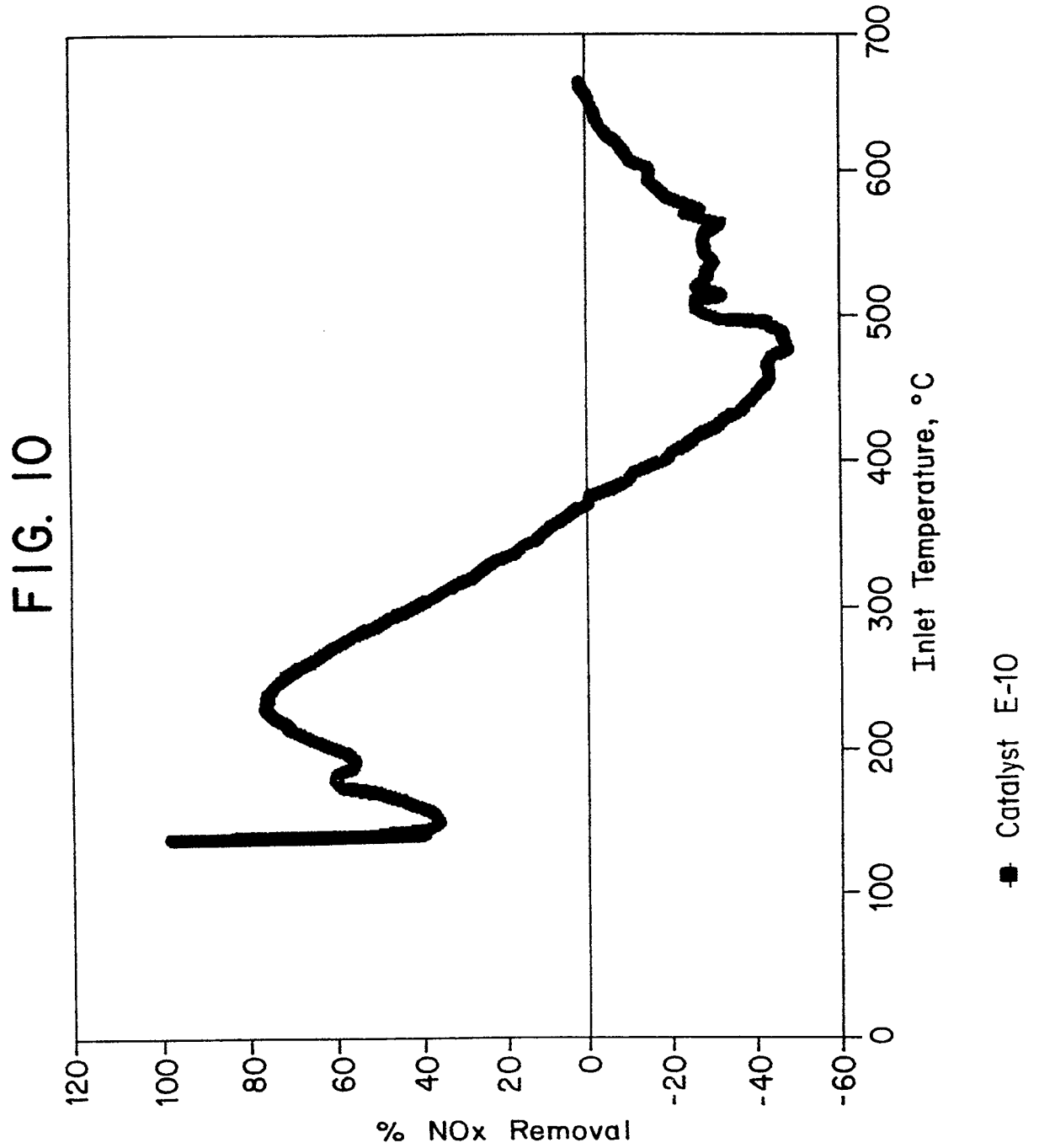
FIG. 8



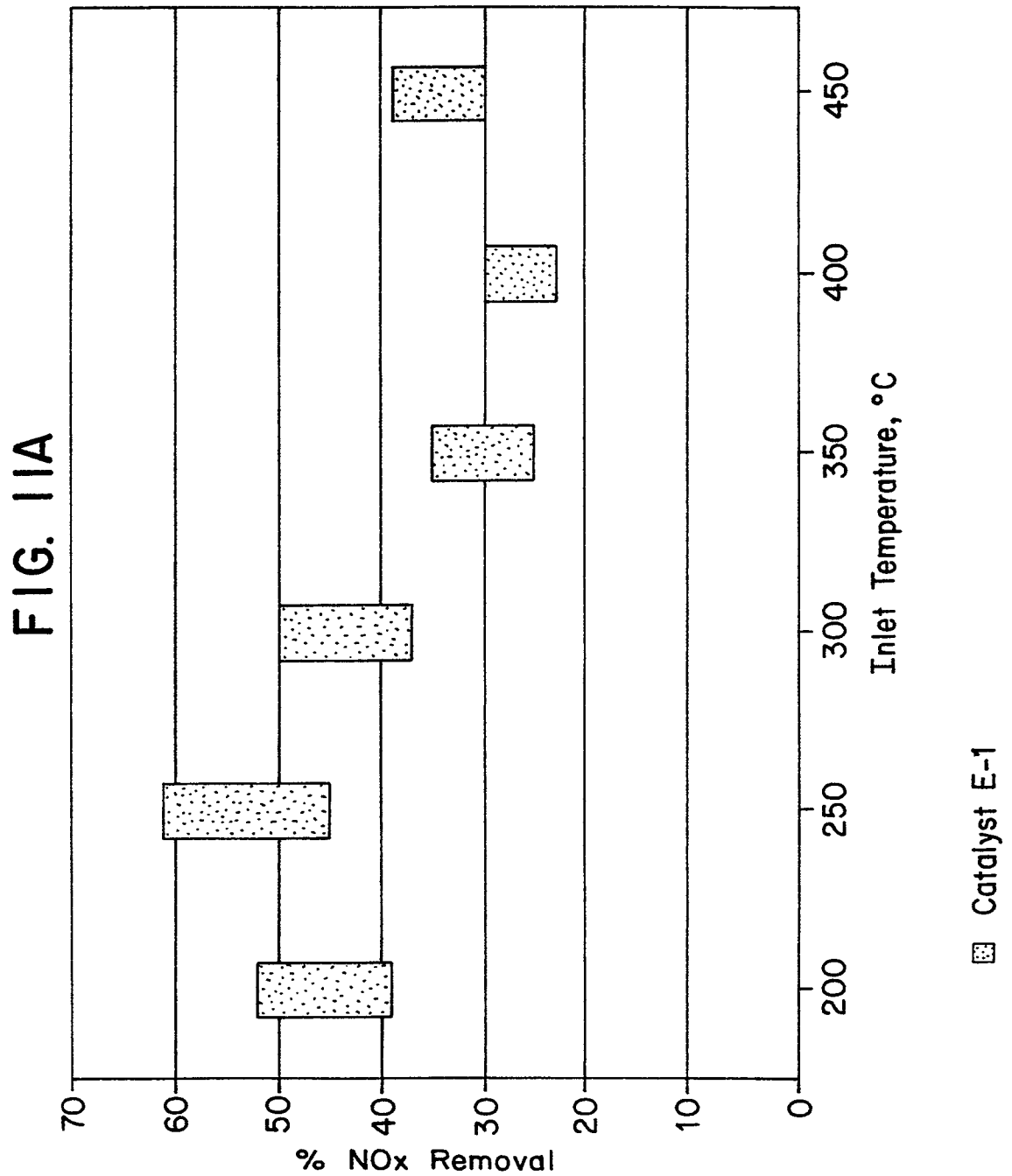
11 / 15



12 / 15

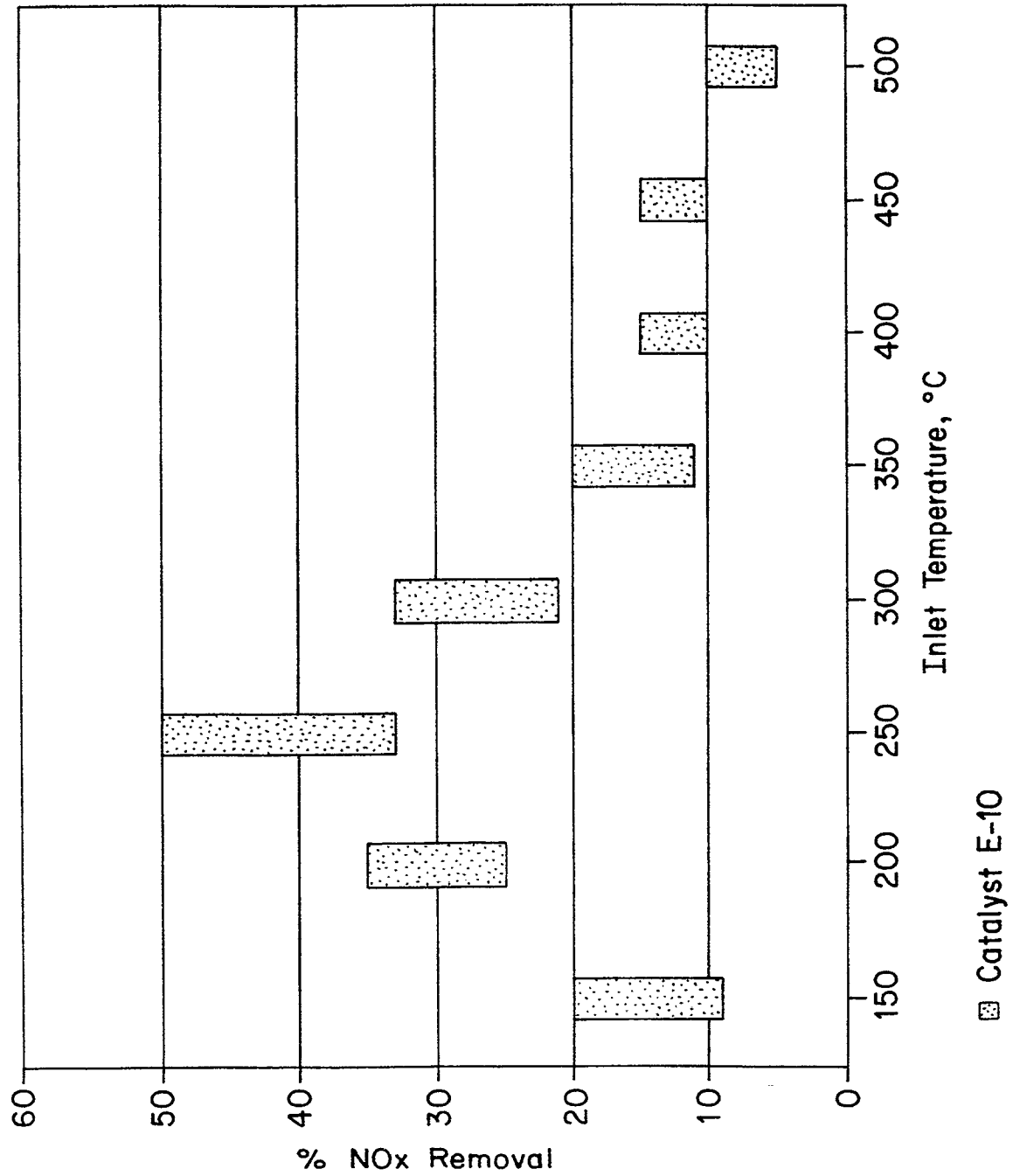


13 / 15



14 / 15

FIG. 11B



SUBSTITUTE SHEET (RULE 26)

15 / 15

