No. 2016-1770

UNITED STATES COURT OF APPEALS FOR THE FEDERAL CIRCUIT

BASF CORPORATION,

Plaintiff-Appellant,

v.

JOHNSON MATTHEY INC.,

Defendant-Appellee.

Appeal from the United States District Court for the District of Delaware, case no. 1:14-cv-01204-SLR-SRF, Judge Sue L. Robinson

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OCTOBER 21, 2016

CERTIFICATE OF INTEREST

Counsel for appellant BASF Corporation certifies the following:

1. The full name of every party or amicus represented by me is:

BASF Corporation

2. The name of the real party in interest (if the party named in the caption is not the real party in interest) represented by me is:

N/A

3. All parent corporations and any publicly held companies that own 10% or more of the stock of the party or amicus curiae represented by me are:

BASF Corporation is a wholly owned subsidiary of BASF Americas Corporation. BASF Americas Corporation is a wholly owned subsidiary of BASFIN Corporation. BASFIN Corporation is a majority owned subsidiary of BASF USA Holding LLC, a Delaware limited liability company. BASF USA Holding LLC is a wholly owned subsidiary of BASF Nederland BV, a Dutch limited liability company. BASF Nederland BV is a wholly owned subsidiary of BASF SE (Societas Europaea – "SE"), a publicly traded European company.

No public corporation, company or other publicly held entity owns 10% or more of the stock of BASF Corporation.

4. The names of all law firms and the partners or associates that appeared for the party or amicus now represented by me in the trial court or are expected to appear in this court are:

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Dated: October 21, 2016 /s/ Deanne E. Maynard

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STATEMENT OF RELATED CASES

No appeal from this proceeding has previously been before this Court or any other court. Counsel for appellant BASF Corporation ("BASF") know of no other cases pending in this Court or any other court that will directly affect or be affected by this Court's decision in this appeal.

JURISDICTIONAL STATEMENT

The district court had jurisdiction under 28 U.S.C. § 1338. It entered final judgment on February 29, 2016. BASF timely appealed on March 28, 2016. This Court has jurisdiction under 28 U.S.C. § 1295(a)(1).

STATEMENT OF THE ISSUE

Whether the claims of U.S. Patent No. 8,524,185 ("'185 patent") are not invalid for indefiniteness due to the "material composition" limitations, which should be construed according to their plain meaning.

INTRODUCTION

BASF and Johnson Matthey Inc. ("JMI") are direct competitors in the mobile emissions control catalyst and catalyst systems industry. BASF owns the '185 patent, which is directed to catalyst systems that control and reduce exhaust emissions of nitrogen oxide ("NO_x") and ammonia ("NH_3") gases into the atmosphere.

The apparatuses claimed in the '185 patent are designed to employ well-known processes for converting NO_x and ammonia into other compounds. Those processes are called selective catalytic reduction ("SCR") of NO_x and ammonia oxidation ("AMOx"). Both of these processes involve catalysts that facilitate the chemical reactions. There are numerous substances known to catalyze SCR of NO_x and numerous substances known to catalyze ammonia oxidation.

The inventors of the ’185 patent did not invent or discover SCR catalysts or ammonia oxidation catalysts, nor did they claim to have done so. What they developed is a particular structure for arranging these catalysts. Before the ’185 patent, using SCR to reduce NO_x and using ammonia oxidation to reduce ammonia could produce harmful byproducts. By arranging SCR and ammonia oxidation catalysts in the particular structure claimed in the ’185 patent, emissions of NO_x and ammonia are reduced, and emission of other harmful byproducts is avoided.

The claims of the ’185 patent thus allow the use of any SCR and ammonia oxidation catalysts as understood in the art of exhaust systems, so long as they are arranged in the particular claimed structure. To apprise persons of ordinary skill in the art that any SCR catalyst can be used in the invention, the claims refer to the SCR catalyst as a material composition “effective to catalyze selective catalytic reduction (SCR) of NO_x.” To apprise persons of ordinary skill in the art that any ammonia oxidation catalyst can be used, the claims refer to the ammonia oxidation catalyst as a material composition “effective for catalyzing NH_3 [i.e., ammonia] oxidation.”

Based on these limitations informing ordinarily skilled artisans that they could use any SCR or ammonia oxidation catalyst as understood in the art of exhaust systems, the district court held all claims of the ’185 patent invalid as

indefinite. The court concluded they were indefinite because they did not "recite a minimum level of function needed to meet this 'effective' limitation nor a particular measurement method to determine whether a composition is 'effective' enough to fall within the claims." Appx5.

That conclusion is contrary to well-established precedent. "Effective" is a commonly used claim term with an ordinary meaning: a material that is "effective" for a particular function means a material that can perform that function. Because claim terms encompass the full breadth of their ordinary meaning, a composition "effective" for a particular function includes any composition that can perform that function, without regard to any minimum level of function.

Under this correct construction, a person of ordinary skill in the art would understand with reasonable certainty what is claimed. A material composition "effective to catalyze selective catalytic reduction (SCR) of NO_x" refers to materials that can catalyze SCR of NO_x, as understood in the art of exhaust systems. Likewise, a material composition "effective for catalyzing NH_3 oxidation" refers to materials that can catalyze ammonia oxidation, as understood in the art of exhaust systems. The '185 patent's specification—which the district court never discussed—contains an extensive, detailed discussion of materials that can catalyze SCR of NO_x and materials that can catalyze ammonia oxidation. The

specification demonstrates that SCR catalysts and ammonia oxidation catalysts were known and in use by persons of skill in the art of exhaust systems before the patent's filing date. Nothing more is required. A person of ordinary skill in the art would understand with reasonable certainty the scope of the '185 patent's claims.

Multiple references in the extrinsic record confirm this. These references show that SCR catalysts and ammonia oxidation catalysts were well known in the field of exhaust systems and that the terms "SCR catalyst" and "ammonia oxidation catalyst" had an understood meaning in the art. The district court's decision did not grapple with any of this evidence.

The judgment of invalidity should be reversed.

STATEMENT OF THE CASE

A. The Prior Art And The '185 Patent

1. Before the 2008 filing date for the claimed invention, selective catalytic reduction (SCR) of NO_x was well known

As the specification of the '185 patent explains, diesel engines produce harmful exhaust gases, including carbon monoxide, partially burned or unburned hydrocarbons, and nitrogen oxides. Appx20 (col.1:13-17). Nitrogen oxides are harmful pollutants and include nitric oxide ("NO") and nitrogen dioxide ("NO_2"); the patent refers to nitrogen oxides collectively as "NO_x." Appx20 (col.1:21-27); Appx26 (col.13:8-11). Diesel engine manufacturers have had to reduce the

emission of harmful NO_x in the exhaust stream to keep pace with increasingly strict emissions standards for diesel engines. Appx20 (col.1:21-23).

A well-known process for reducing NO_x emissions is SCR of NO_x. Appx20 (col.1:21-23). Exhaust gas aftertreatment systems using SCR of NO_x can convert more than 90% of NO_x to harmless compounds. Appx20 (col.1:27-30). In the SCR process, ammonia is deliberately injected into the exhaust stream within the exhaust aftertreatment system. Appx21 (col.3:26-30). The ammonia reacts with the NO_x to convert it into harmless nitrogen gas and water. Appx20 (col.1:23-27). This reaction is performed in the presence of a chemical catalyst—typically a base metal—which catalyzes (i.e., facilitates) the chemical reaction. Appx20 (col.1:26-27). SCR catalysts were "well known and widely used commercially in mobile applications" by the time the inventors filed for the '185 patent in 2008. Appx23 (col.7:58-61).

Extrinsic evidence likewise shows that the use of ammonia and an SCR catalyst to reduce NO_x in exhaust aftertreatment systems was well known before the 2008 filing date. The use of ammonia for SCR of NO_x has been known since 1957. Appx317. By the filing date, materials that performed as SCR catalysts were well known. Appx317; Appx1319-1321. As of 2002, catalyst manufacturers had researched and developed a variety of SCR catalysts, and engine manufacturers increasingly were using SCR catalysts with ammonia to reduce NO_x

in mobile applications such as heavy-duty diesel engines. Appx317; Appx1319; Appx1373.

2. Before the 2008 filing date, ammonia oxidation was well known

As the specification also explains, although SCR removes most NO_x from the exhaust stream, the use of ammonia in the SCR process presents its own concerns. Appx20 (col.1:31-50). Excess ammonia that is not consumed in the SCR reaction can exit the tailpipe and disperse into the air. Appx20 (col.1:31-40). This excess ammonia is called "ammonia slip." Appx20 (col.1:41). Ammonia slip can result in corrosive condensation, strong odors, and eye, throat, and skin irritation. Appx20 (col.1:41-48).

Excess ammonia can be removed in the exhaust aftertreatment system and can be prevented from exiting the tailpipe through a chemical reaction called ammonia oxidation. Appx20 (col.1:49-58). In ammonia oxidation, ammonia molecules combine with oxygen molecules and are converted mostly to NO and water. Appx22 (col.5:40-47). Ammonia oxidation is performed in the presence of a chemical catalyst—an ammonia oxidation catalyst—to increase the extent to which ammonia molecules are consumed in the chemical reaction. Appx20 (col.1:50-52). While using catalysts to facilitate ammonia oxidation was known before the '185 patent, ammonia oxidation introduced its own problems because

one of the byproducts of ammonia oxidation, NO (i.e., nitric oxide gas), is a form of NO_x. Appx20 (col.1:52-58).

Extrinsic evidence also showed that by the time of the 2008 filing date, it was known to persons of ordinary skill in the art that certain materials catalyzed ammonia oxidation in mobile applications such as heavy-duty diesel engines. Appx1321. For example, precious metals such as platinum were known ammonia oxidation catalysts for mobile applications. Appx1321-1322; Appx1383-1384. Multiple scientific publications in the record discuss materials that catalyze ammonia oxidation. Appx990-1145.

3. The '185 patent claims a new structure for arranging SCR and ammonia oxidation catalysts

a. The claims require a particular arrangement of catalysts in distinct washcoat layers

The '185 patent discloses a new catalyst system for diesel engine exhaust that uses SCR to reduce NO_x emissions and ammonia oxidation to reduce excess ammonia, all while minimizing harmful byproducts. The patent is directed to a specific arrangement of SCR catalysts and ammonia oxidation catalysts to convert NO_x *and* excess ammonia into harmless nitrogen gas ("N_2"). Appx20 (col.1:10-58).

In the invention, each catalyst is coated onto a substrate—typically a ceramic honeycomb structure. Appx22 (col.5:8-10, col.5:60-63). Any suitable

substrate may be used, including commercially available ones. Appx22 (col.5:63-64, col.6:10-39). Substrates typically have many fine, parallel gas-flow passages extending from an inlet end (where exhaust gas enters) to an outlet end (where exhaust gas exits). Appx22 (col.5:63-67).

The substrate is coated with the catalyst materials on the interior walls of the fine gas-flow passages so that the gases flowing through the passages contact the catalysts. Appx22 (col.5:67-col.6:4). The catalysts are coated onto the walls of the substrate in "washcoat" layers—distinct layers of material disposed on the substrate surface. Appx22 (col.5:8-15). A finished coated substrate is placed within the aftertreatment system, through which the exhaust gas flows. Appx25 (col.11:40-47).

The claims of the '185 patent require at least two washcoat layers. First, an "undercoat washcoat layer" containing an ammonia oxidation catalyst is coated onto the substrate, covering the substrate's outlet end but not covering the total length of the substrate. Appx29 (col.19:43-47, col.20:48-51, col.20:58-60). Second, an "overcoat washcoat layer" containing an SCR catalyst is coated over the total length of the substrate, also covering the undercoat washcoat layer. Appx29 (col.19:48-52, col.20:52-57). It is this architecture—rather than the constituent materials of each layer alone—that furthers the goals of reducing emission of both NO_x and excess ammonia without producing harmful byproducts.

Appx20 (col.1:10-58). And it is this architecture, not some new material composition, that the inventors claimed as novel. *See* Appx25 (col.11:9-14).

Figures 1(a) and 1(b) from the '185 patent illustrate the architecture:

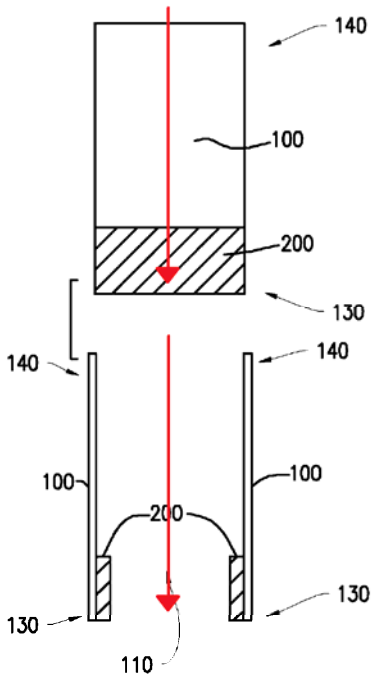


FIG. 1(a)

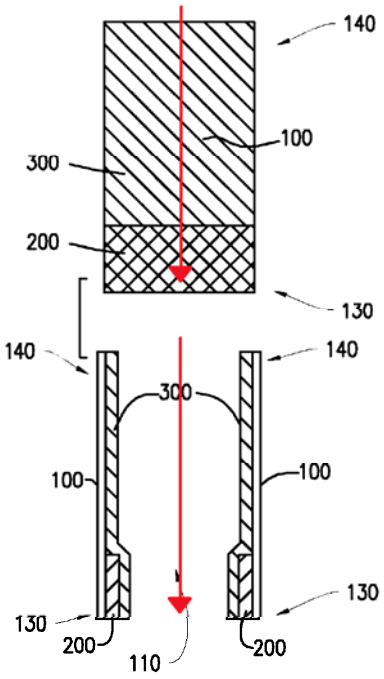


FIG. 1(b)

Appx10 (arrows added to indicate direction of gas flow). These figures depict only a single gas-flow passage within the substrate; the complete substrate might contain 100-1000 identical channels per square inch in a honeycomb pattern. Appx24 (col.10:46-52). The upper portions of the figures show a surface of a wall of the channel. The bottom portions of the figures show a cross-section of a channel, with walls (100) on each side and the gas-flow passage (110) in the middle.

In Figure 1(a), the undercoat washcoat layer (200) containing an ammonia oxidation catalyst has been applied, coating the outlet end of the channel, but not covering the total length of the channel. Appx24 (col.10:52-56). In Figure 1(b), the overcoat washcoat layer (300) containing an SCR catalyst has been applied. The overcoat washcoat layer covers the entire length of the substrate and covers the undercoat washcoat layer. Appx24 (col.10:62-65).

After the washcoat layers are formed, the resulting channel has (1) an upstream or inlet zone that has a layer containing an SCR catalyst and (2) a downstream or outlet zone that has at least two distinct layers—an overcoat washcoat layer with an SCR catalyst and an undercoat washcoat layer with an ammonia oxidation catalyst. Appx25 (col.11:15-20).

The claims of the '185 patent do not require the use of any particular SCR catalyst or ammonia oxidation catalyst. Rather, to apprise persons of ordinary skill in the art of exhaust systems that the undercoat washcoat layer can contain any ammonia oxidation catalyst as understood in the art, claim 1 recites that the undercoat washcoat layer contains "a material composition A effective for catalyzing NH3 oxidation." Appx29 (col.19:46-47); *see* Appx29 (col.20:49-51) (claim 17 requiring an undercoat washcoat layer containing "a material composition A comprising a precious metal effective for catalyzing NH_3 oxidation"). Likewise, to apprise persons of ordinary skill that the overcoat

washcoat layer can contain any SCR catalyst as understood in the art, claim 1 recites that the overcoat washcoat layer contains "a material composition B effective to catalyze selective catalytic reduction (SCR) of NOx." Appx29 (col.19:51-52); *see* Appx29 (col.20:55-57) (claim 17 requiring an overcoat washcoat layer containing "a material composition B free from precious metal effective for catalyzing selective catalytic reduction (SCR) of NO_x").

Independent claim 1 recites:

> 1. A catalyst system for treating an exhaust gas stream containing NOx, the system comprising:
>
> at least one monolithic catalyst substrate having an inlet end and an outlet end; an undercoat washcoat layer coated on the outlet end of the monolithic substrate and which covers less than 100% of the total length of the monolithic substrate, and containing *a material composition A effective for catalyzing NH3 oxidation*;
>
> an overcoat washcoat layer coated over a total length of the monolithic substrate from the inlet end to the outlet end sufficient to overlay the undercoat washcoat layer, and containing *a material composition B effective to catalyze selective catalytic reduction (SCR) of NOx*; and
>
> wherein material composition A and material composition B are maintained as physically separate catalytic compositions.

Appx29 (col.19:39-55) (disputed claim terms italicized); *see* Appx30 (certificate of correction). Claims 2 to 16 depend from claim 1. Appx29 (col.19:56-col.20:41).

Independent claim 17 recites:

> 17. A catalyst system for treating an exhaust gas stream containing NO_x, the system comprising:
> at least one flow-through honeycomb substrate comprising a plurality of fine, substantially parallel gas flow passages extending along the longitudinal axis of the substrate;
> an undercoat washcoat layer coated on the outlet end of the honeycomb substrate, and containing *a material composition A comprising a precious metal effective for catalyzing NH_3 oxidation*;
> an overcoat washcoat layer coated over a total length of the honeycomb substrate from the inlet end to the outlet end of the substrate sufficient to overlay the undercoat washcoat layer, and containing *a material composition B free from precious metal effective for catalyzing selective catalytic reduction (SCR) of NO_x*;
> wherein the undercoat washcoat layer covers in the range of about 10% to about 40% of the total honeycomb substrate length, and wherein material composition A and material composition B are maintained as physically separate catalytic compositions.

Appx29 (col.20:42-62) (disputed claim terms italicized).

b. The claimed arrangement of catalysts beneficially causes both NO_x and excess ammonia to be converted to harmless nitrogen gas

In operation, when exhaust gas and injected ammonia enter the upstream zone, they come into contact with the SCR catalyst in the overcoat washcoat layer (300), and NO_x and ammonia react to produce nitrogen gas and water. Appx25

(col.11:40-47). The upstream zone is primarily responsible for removing NO_x emissions from the exhaust through SCR. Appx25 (col.12:37-39).

Excess ammonia that is not consumed in the upstream zone moves into the downstream zone, which has two distinct catalyst layers. Appx25 (col.12:12-18). Figure 2 illustrates the process of excess ammonia passing through the downstream zone to be converted into nitrogen gas:

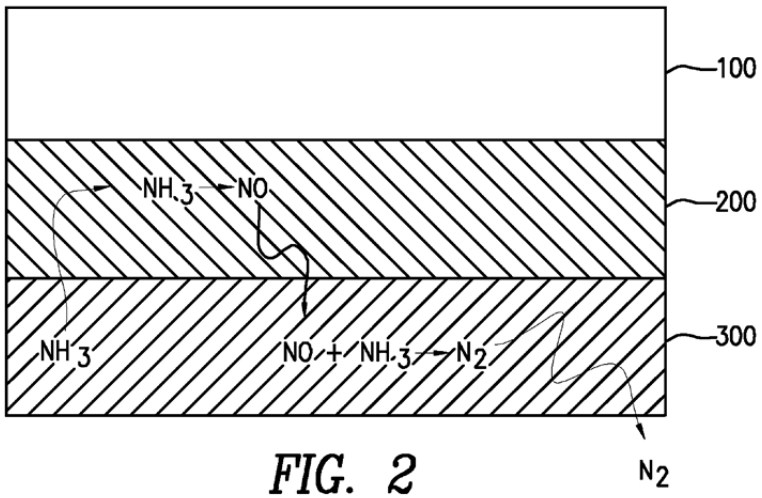


FIG. 2

Appx11 (showing a cross-section of the outlet zone, with chamber wall (100) on top, undercoat washcoat layer (200) in the middle, and overcoat washcoat layer (300) on the bottom of the figure); Appx25 (col.12:18-27). The excess ammonia diffuses through the overcoat washcoat layer (300) and comes into contact with the ammonia oxidation catalyst in the undercoat washcoat layer (200). Appx25 (col.12:18-23). In the undercoat washcoat layer (200), the ammonia reacts with oxygen and is initially converted to NO. The NO diffuses to the overcoat washcoat layer (300), where it comes into contact with the SCR catalyst and reacts with

additional unconsumed ammonia to form harmless nitrogen gas. Appx25 (col.12:23-27). The downstream zone with distinct dual layers thus increases the likelihood that potentially harmful NO produced during ammonia oxidation will ultimately be converted into harmless nitrogen gas. Appx25 (col.12:25-36).

c. The particular arrangement of the washcoat layers improves performance regardless of which catalysts are used

Having a downstream zone with distinct, overlapping washcoat layers plays an important role in the invention. The specification explains that the invention's "two-layer outlet zone that physically separates the NH_3 oxidation component and the SCR component is an important feature affecting the performance of the catalyst, and distinguishes this particular methodology for preparation of an integrated SCR+AMOx catalyst." Appx25 (col.11:9-14).

Indeed, the inventors described experiments in which they observed that using a two-layer catalyst architecture provided advantages compared to using the same catalyst materials mixed together and formed as a single layer on a substrate. In these experiments, the inventors compared the gas conversion properties of a two-layer architecture—an SCR catalyst layer over an ammonia oxidation catalyst layer on a substrate—to the conversion properties of the mixed single-layer architecture. Appx26-27 (col.13:61-col.15:2). The inventors measured the extent to which excess ammonia was converted into harmless nitrogen gas as opposed to

potentially harmful byproducts such as NO. When the same catalyst materials were used in each architecture, the layered architecture outperformed the mixed architecture regardless of which SCR catalyst and ammonia oxidation catalyst were used. Appx16 (FIG. 7), Appx26 (Table 1), Appx27 (col.16:20-37).

d. The specification defines the function that the "material composition" limitations must perform and provides numerous examples of such materials

The '185 patent's specification expressly defines the catalyzing functions that the claimed "material compositions" must perform. The specification defines "SCR function" as a "chemical process in which NO_x and NH_3 are combined to produce preferably N_2." Appx22 (col.5:33-38). It defines "NH_3 oxidation function" as "a process in which NH_3 is reacted with oxygen to produce NO, NO_2, N_2O, or preferably N_2." Appx22 (col.5:40-47). The specification also gives an exact chemical equation for each reaction. Appx22 (col.5:35, 44).

The claims also identify materials that can catalyze SCR of NO_x and materials that can catalyze ammonia oxidation. Claims 6, 8, 9, 10, and 11 identify exemplary material compositions effective to catalyze SCR of NO_x. Claim 6 recites that "the material composition B contains a zeolitic or non-zeolitic molecular sieve." Appx29 (col.20:6-8). Claim 8 recites that "the material composition B contains an aluminosilicate molecular sieve having a CHA crystal framework type." Appx29 (col.20:12-14). Claim 9 recites that "the material

composition B contains a silicoaluminophosphate molecular sieve having the CHA crystal framework type." Appx29 (col.20:15-17). Claim 10 recites that "the molecular sieve contains a metal from one of the groups VB, V[I]B, VIIB, VIIIB, IB, or IIB of the periodic table distributed on or within the molecular sieve, the metal being present in an amount between 0.1% and 10% by wt. of the molecular sieve." Appx29 (col.20:18-23). Claim 11 recites that "the metal is selected from Cu, Fe, and mixtures or combinations thereof." Appx29 (col.20:23-24).

Claims 14, 15, and 16 provide exemplary material compositions effective for catalyzing ammonia oxidation. Claim 14 recites that the "material composition A comprises a precious metal component dispersed on support particles." Appx29 (col.20:29-31). Claim 15 recites that "the support particles comprise a refractory metal oxide containing alumina, silica, zirconia, titania, ceria, and physical mixtures or chemical combinations thereof, including atomically doped combinations." Appx29 (col.20:32-36). And claim 16 recites that "the precious metal component comprises ruthenium, rhodium, iridium, palladium, platinum, silver, or gold and physical mixtures or chemical combinations thereof, including atomically doped combinations." Appx29 (col.20:37-41).

The specification provides additional details regarding material compositions that can catalyze SCR of NO_x and ammonia oxidation. The specification includes sections titled "SCR Composition" and "NH_3 Oxidation

Composition" that discuss the chemical components and structure of SCR and ammonia oxidation catalysts. Appx22-23 (col.6:47-col.8:57). According to the specification, an SCR catalyst may be "a microporous inorganic framework or molecular sieve onto which a metal from one of the groups VB, VIB, VIIB, VIIIB, IB, or IIB of the periodic table has been deposited." Appx22 (col.6:56-60). The specification discusses the weight of metals in the SCR compositions, as well as the types of microporous inorganic frameworks that can be used. Appx23 (col.7:1-22). Specific examples of metals that can be used include iron, copper, and zinc. Appx22-23 (col.6:56-67, col.7:41-47). And "SCR compositions consisting of vanadium supported on a refractory metal oxide such as alumina, silica, zirconia, titania, ceria and combinations thereof are also well known and widely used commercially in mobile applications." Appx23 (col.7:58-61).

The disclosed examples of ammonia oxidation catalysts include materials that support various precious metals, such as ruthenium, rhodium, iridium, palladium, platinum, silver, and gold. Appx23 (col.8:11-19). The specification also discusses the weight of precious metals in the ammonia oxidation compositions and the types of support materials that may be used. Appx23 (col.8:19-47). Examples of suitable support materials include alumina, silica, titania, ceria, and zirconia. Appx23 (col.8:24-36).

B. The District Court's Indefiniteness Ruling

BASF sued JMI, alleging that JMI infringes claims of the '185 patent by manufacturing, offering for sale, and selling in the United States catalyst systems covered by the patent. Appx46-47.

1. The parties' positions on claim construction

During claim construction, BASF proposed that "material composition A effective for catalyzing NH_3 oxidation" be construed according to its "[p]lain and ordinary meaning: a material composition A effective for catalyzing NH_3 oxidation as understood in the art of exhaust systems." Appx84. JMI argued that the limitation rendered the claims indefinite. Appx84. JMI alternatively proposed that the limitation "should be construed according to its plain meaning, as any material effective for catalyzing NH_3 oxidation." Appx84.

BASF also proposed that "material composition B effective to catalyze selective catalytic reduction (SCR) of NO_x" be construed according to its "[p]lain and ordinary meaning: a material composition B effective to catalyze selective catalytic reduction (SCR) of NO_x as understood in the art of exhaust systems." Appx85. JMI argued that the limitation left the claims indefinite. Appx85. JMI alternatively proposed that the limitation "should be construed according to its plain meaning, as any material effective to catalyze selective catalytic reduction (SCR) of NO_x." Appx85.

In contending that the claims are not indefinite, BASF relied primarily on the disclosures in the intrinsic record. Appx105-113; *supra* pp. 15-17. Both parties also submitted expert declarations and prior art references discussing the use of SCR catalysts and ammonia oxidation catalysts before the 2008 filing date. Appx313-320; Appx347-366; Appx950-962; Appx990-1156; Appx1314-1352; Appx1377-1387; Appx1408-1411. BASF's expert, Dr. Crocker, explained that material compositions effective for catalyzing SCR of NO_x and ammonia oxidation in a catalyst system for treating engine exhaust gas "were known to persons of ordinary skill at the time of the effective filing date." Appx1318.

JMI's expert, Dr. Epling, also identified numerous materials that can be effective to catalyze SCR of NO_x or ammonia oxidation. Appx953-958. While he offered an opinion on the legal question of indefiniteness, that opinion was based on JMI's argument that the '185 patent is indefinite unless it defines "the level of function required to be considered 'effective.'" Appx956. Under BASF's construction of the "material composition" limitations, Dr. Epling had no trouble identifying materials that can catalyze SCR of NO_x and ammonia oxidation within the operating conditions of an exhaust aftertreatment system. Appx953-955. Indeed, he acknowledged that there are "objective standards in this field" that allow persons of ordinary skill in the art to determine whether and to what extent a material performs as a catalyst. Appx957.

2. The district court held the claims indefinite based on the claim term "effective" and without discussing the disclosures in the specification

After hearing oral argument, the district court held all claims of the '185 patent invalid as indefinite under 35 U.S.C. § 112 ¶ 2 (pre-Leahy-Smith America Invents Act, which applies here). Appx4-5; Appx7.

The district court quoted the claim language and held that the use of the functional term "effective" rendered the claims indefinite. The indefiniteness ruling and rationale is set forth in full here:

> 5. Claim 1 recites an undercoat washcoat layer containing a "material composition A effective for catalyzing NH3 oxidation" and an overcoat washcoat layer containing "a material composition B effective to catalyze selective catalytic reduction (SCR) of NOx." (9:41-47) Claim 5 recites "a material composition further effective to catalyze SCR of NOx." (20:3-5) Claim 17 recites an overcoat washcoat layer containing "a material composition B free from precious metal effective for catalyzing selective catalytic reduction (SCR) of NOx." (20:42-62) Each claim fails to limit the "material composition A" or the "material composition B" to any specific materials. Rather than explicitly defining the material compositions, the claims utilize functional language, specifically "effective," to purportedly define them. In other words, the claims recite a performance property the composition must display, rather than its actual composition. Moreover, none of the claims recite a minimum level of function needed to meet this "effective" limitation nor a particular measurement method to determine whether a composition is "effective" enough to fall within the claims.[10] Without such information, a person of ordinary skill in the art could not determine which materials are

> within the "material composition A" or "material composition B" limitation, and which are not. *Nautilus,* 134 S. Ct. at 2129 ("a patent must be precise enough to afford clear notice of what is claimed, thereby appris[ing] the public of what is still open to them"). Lacking sufficient detail defining "material composition A" and "material composition B," the court concludes that the disputed limitations are not "precise enough to afford clear notice of what is claimed" and do not provide reasonable certainty as to the scope of the invention. *Id.*
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> ---
>
> [10] The court additionally notes that "a practically limitless number of materials" exist that would "catalyze SCR of NOx, even within the normal operating conditions of an exhaust aftertreatment system," indicating that the claims, as written, fail to sufficiently identify the material compositions. (D. I. 102 at ¶ 22)

Appx4-5 & n.10.

This ruling did not mention, much less distinguish, decisions from this Court concerning functional claiming and the well-settled meaning of "effective." It did not discuss any of the disclosures of SCR catalysts and ammonia oxidation catalysts in the specification. Nor did the district court discuss any of the extrinsic evidence showing that SCR catalysts and ammonia oxidation catalysts were known to ordinarily skilled artisans.

SUMMARY OF ARGUMENT

I.A. De novo review applies to all aspects of the indefiniteness ruling at issue in this appeal. When, as here, the indefiniteness inquiry is intertwined with claim construction and can be resolved by reference to the intrinsic record and the undisputed facts, this Court reviews the issue de novo. The district court here

made no factual findings. Its decision focused on the claim language, without addressing any of the specification's detailed disclosures. This appeal thus presents only legal issues.

B. The disputed claim limitations require material compositions "effective to catalyze" or "effective for catalyzing" specific chemical reactions—SCR of NO_x and ammonia oxidation, respectively. These limitations define the required material compositions functionally, that is, by what they do rather than what they are. Defining claim elements functionally does not make them indefinite; it is a well-accepted way of drafting claims.

"Effective" is a functional limitation with an ordinary meaning. A claim reciting a material composition "effective for" a function requires a material composition that is able to effect, or perform, that function. This Court consistently has interpreted "effective" according to that plain meaning. This Court's precedent also establishes that claims with functional terms like "effective" must be given their full scope—they cover any and all embodiments that can perform the recited function; they do not require any minimum level of function.

Here, the claims use "effective" for its ordinary meaning and should be given their full scope. A "material composition A effective for catalyzing NH_3 oxidation" includes any material composition understood in the art of exhaust systems to perform catalysis of NH_3 oxidation. Likewise, a "material composition

B effective to catalyze SCR of NO_x" includes any material composition understood in the art to perform catalysis of SCR of NO_x.

Instead of giving the claims their plain meaning, the district court held them indefinite. But the fact that the claims do not recite a minimum level of catalysis necessary for a material to be deemed "effective" or a measurement method to determine whether a composition is "effective enough" does not make them indefinite. It just means that the claims lack those limitations and thus should be given the full scope of their ordinary meaning. That some limitations in each claim may be broad does not make the claims themselves indefinite.

C. Under the correct claim construction, a person of ordinary skill in the art would understand with reasonable certainty the scope of the "material composition" limitations. The claims identify each function that each material composition must perform by name. The specification gives detailed descriptions of the named functions, even providing exact chemical formulas. And the specification explains that materials for performing these functions were well known in the art of exhaust systems at the time of filing.

These detailed descriptions in the intrinsic record are enough to satisfy the reasonable certainty standard. Yet the specification does not stop there. It also provides numerous examples of material compositions known and used in the art of exhaust systems for performing the claimed catalytic functions. It identifies

examples by exact material composition and structure. Based on the ordinary meaning of "effective" and the extensive disclosures in the specification, this Court can and should reverse the district court's indefiniteness judgment as a matter of law.

II.A. Were this Court to consider the extrinsic evidence, however, it likewise compels the conclusion that JMI failed to carry its burden of establishing indefiniteness by clear and convincing evidence. Under the correct claim construction, there is no genuine dispute of material fact pertinent to the indefiniteness analysis; the extrinsic evidence proffered by both sides demonstrates that persons of ordinary skill in the art would understand the scope of the claims with reasonable certainty.

The undisputed extrinsic evidence demonstrates that material compositions that can catalyze SCR of NO_x and ammonia oxidation were broadly known and used in the field of exhaust systems by the 2008 filing date. Both parties' experts explained that persons of skill in the art were familiar with such materials and used them for the same purposes as claimed in the '185 patent. Indeed, both experts referred to such materials using the same terms as the '185 patent—SCR catalyst and ammonia oxidation. That background knowledge reinforces what the intrinsic record already makes clear—persons of ordinary skill in the art would understand with reasonable certainty what the claims encompass.

Accordingly, if the Court were to deem it necessary to look beyond the intrinsic evidence, it should reverse the judgment of indefiniteness based on the intrinsic and undisputed extrinsic evidence.

B. Were this Court to conclude, however, that consideration of the extrinsic evidence is necessary and its meaning is uncertain, the burden would fall on JMI to overcome that uncertainty and prove by clear and convincing evidence that the claims are indefinite. At a minimum, therefore, vacatur and remand would be required for the district court to determine whether JMI has met that burden.

STANDARD OF REVIEW

Where, as here, a district court holds a patent invalid as indefinite based on the intrinsic record and without making any factual findings, this Court reviews all aspects of the indefiniteness ruling de novo. *Biosig Instruments, Inc. v. Nautilus, Inc.*, 783 F.3d 1374, 1377-78 (Fed. Cir. 2015); *see infra* Part I.A.

ARGUMENT

Patents are presumed valid, and the challenger bears the burden of proving invalidity by clear and convincing evidence. 35 U.S.C. § 282; *Microsoft Corp. v. i4i Ltd. P'ship*, 131 S. Ct. 2238, 2241 (2011). To prove indefiniteness, the challenger must demonstrate that the "claims, read in light of the specification delineating the patent, and the prosecution history, fail to inform, with reasonable certainty, those skilled in the art about the scope of the invention." *Nautilus, Inc.*

v. Biosig Instruments, Inc., 134 S. Ct. 2120, 2124, 2129 (2014). The inquiry "trains on the understanding of a skilled artisan at the time of the patent application." *Id.* at 2130. The "reasonable certainty" standard does not require "'absolute or mathematical precision.'" *Biosig*, 783 F.3d at 1381 (quoting *Interval Licensing LLC v. AOL, Inc.*, 766 F.3d 1364, 1370-71 (Fed. Cir. 2014)). Rather, it "must take into account the inherent limitations of language." *Nautilus*, 134 S. Ct. at 2128.

I. JMI CANNOT OVERCOME THE PRESUMPTION OF VALIDITY BECAUSE THE INTRINSIC RECORD INFORMS AN ORDINARILY SKILLED ARTISAN OF THE SCOPE OF THE CLAIMS WITH REASONABLE CERTAINTY

JMI cannot overcome the presumption of validity here because, when the claims of the '185 patent are correctly construed, the intrinsic record informs one of ordinary skill in the art of their scope with reasonable certainty. *Id.* at 2124.

A. This Court's Review Is De Novo In All Respects

As an initial matter, de novo review applies to all aspects of the indefiniteness ruling at issue in this appeal. "In the face of an allegation of indefiniteness, general principles of claim construction apply." *Biosig*, 783 F.3d at 1377-78 (quoting *Enzo Biochem, Inc. v. Applera Corp.*, 599 F.3d 1325, 1332 (Fed. Cir. 2010)). "In that regard, claim construction involves consideration of primarily the intrinsic evidence, *viz.*, the claim language, the specification, and the prosecution history." *Id.* at 1378 (quoting *Enzo*, 599 F.3d at 1332). "The words of

a claim are generally given their ordinary and customary meaning as understood by a person of ordinary skill in the art when read in the context of the specification and prosecution history." *Thorner v. Sony Comput. Entm't Am. LLC*, 669 F.3d 1362, 1365-67 (Fed Cir. 2012).

Where a district court's indefiniteness ruling is based on the intrinsic evidence, the ruling "will amount solely to a determination of law, and the Court of Appeals will review that construction de novo." *Biosig*, 783 F.3d at 1378 (quoting *Teva Pharm. USA, Inc. v. Sandoz, Inc.*, 135 S. Ct. 831, 841 (2015)). The issue is likewise purely legal when the definiteness inquiry is intertwined with claim construction and "the meaning of the claim at issue is clear in view of the intrinsic record and undisputed facts." *Eidos Display, LLC v. AU Optronics Corp.*, 779 F.3d 1360, 1364-65 (Fed. Cir. 2015). Although any underlying factual determinations based on extrinsic evidence would be reviewed for clear error, "it is not enough that the district court may have heard extrinsic evidence during a claim construction proceeding—rather, the district court must have actually made a factual finding in order to trigger *Teva*'s deferential review." *CardSoft, LLC v. VeriFone, Inc.*, 807 F.3d 1346, 1350 (Fed. Cir. 2015).

Here, the district court made no factual findings. Appx4-5. Instead, it focused on the language of the claims. The decision did not mention, much less analyze, other intrinsic evidence. It thus did not deal with any of the

specification's detailed disclosures of SCR catalysts and ammonia oxidation catalysts. Appx4-5; *see supra* pp. 15-17; *infra* Part I.C.2. Nor did the decision mention the extensive extrinsic evidence demonstrating that persons of ordinary skill in the art understood what SCR catalysts and ammonia oxidation catalysts are and regularly used them. Appx4-5; *see infra* Part II.A.

In a footnote, the district court did "note[]" that "'a practically limitless number of materials' exist that would 'catalyze SCR of NO_x, even within the normal operating conditions of an exhaust aftertreatment system.'" Appx5 n.10 (quoting expert declaration). That was the district court's only reference to extrinsic evidence, and the court did not expressly make a finding of fact. Even were that deemed a factual finding, the breadth of the claims has no legal bearing on indefiniteness, as explained below. *See infra* Part I.B.3. The issues presented by the indefiniteness ruling thus are all legal ones, reviewed de novo.

B. "Effective" Is A Functional Term With An Ordinary Meaning And Does Not Render The Claims Indefinite

1. A material composition "effective" for a function is a composition that can perform the function

As the district court observed, the claim limitations at issue here employ "functional language, specifically 'effective.'" Appx5; *see* Appx372. A functional limitation defines something "by what it does rather than by what it is." *In re Swinehart*, 439 F.2d 210, 212 (C.C.P.A. 1971). Here, the claims require that the

undercoat washcoat layer contain a material composition "effective for catalyzing NH_3 oxidation" and that the overcoat washcoat layer contain a material composition "effective to catalyze selective catalytic reduction (SCR) of NO_x." Appx29 (col.19:46-47, col.19:51-52); *see* Appx29 (col.20:50-51, col.20:56-57).

Contrary to the district court's conclusion (Appx5), the use of functional language does not suggest that claims are indefinite. It is well established that "defining a particular claim term by its function is not improper." *Hill-Rom Servs., Inc. v. Stryker Corp.*, 755 F.3d 1367, 1374-75 (Fed. Cir. 2014). As this Court's predecessor explained forty-five years ago, "there is nothing intrinsically wrong with the use of such a technique in drafting patent claims." *Swinehart*, 439 F.2d at 212. This Court recently reiterated that claims "are not per se indefinite merely because they contain functional language." *Cox Commc'ns, Inc. v. Sprint Commc'n Co.*, --- F.3d ---, No. 16-1013, 2016 WL 5335038, at *5 (Fed. Cir. Sept. 23, 2016); *see Microprocessor Enhancement Corp. v. Tex. Instruments Inc.*, 520 F.3d 1367, 1375 (Fed. Cir. 2008) ("apparatus claims are not necessarily indefinite for using functional language"). Indeed, given the limitations inherent in language, there sometimes is a "practical necessity for the use of functional language." *Swinehart*, 439 F.2d at 212. "Many devices take their names from the functions they perform. The examples are innumerable, such as 'filter,' 'brake,'

'clamp,' 'screwdriver,' or 'lock.'" *Greenberg v. Ethicon Endo-Surgery, Inc.*, 91 F.3d 1580, 1583 (Fed. Cir. 1996); *see Hill-Rom*, 755 F.3d at 1374-75 (same).

"Effective" is such a functional term. As this Court repeatedly has recognized, the ordinary meaning of "effective" is that a claimed component can effect or perform a particular function. *See Cross Med. Prods., Inc. v. Medtronic Sofamor Danek, Inc.*, 424 F.3d 1293, 1306 (Fed. Cir. 2005).

For example, in *Leggett & Platt, Inc. v. VUTEk, Inc.*, the Court equated "effective to" with "able to." 537 F.3d 1349, 1354 (Fed. Cir. 2008). The claim at issue required a cold UV curing assembly "*effective to* impinge sufficient UV light on the ink to substantially cure the ink." *Id.* at 1352 (emphasis added). The Court explained that "the claim is written with functional rather than structural language—it requires the cold UV assembly to be 'effective to' substantially cure rather than requiring ink to be substantially cured." *Id.* at 1354. The Court thus held that the claim would be anticipated by a prior art cold UV assembly so long as the prior art was "*able to*" substantially cure the ink. *Id.* (emphasis added).

Likewise, in *Cross Medical*, the Court equated "effectively" with "operatively"—a functional term requiring structure that can perform the named function. In *Cross Medical*, this Court explained that "operatively" is "often used descriptively in patent drafting to mean 'effectively' in describing the functional relationship between claimed components." 424 F.3d at 1306. The claim term at

issue in *Cross Medical* was "operatively joined," and the required function was "posterior stabilization." *Id.* at 1305-06. The Court thus construed "operatively joined" as requiring that the components be "connected and in contact such that the device is *effective to* perform posterior stabilization." *Id.* at 1306 (emphasis added).

The Court similarly construed "effective" in *Abbott Laboratories v. Baxter Pharmaceutical Products, Inc.*, 334 F.3d 1274 (Fed. Cir. 2003). There, the Court construed the term "amount effective to prevent degradation by a Lewis acid of said quantity of sevoflurane." *Id.* at 1276 (emphasis omitted). The Court explained that "the term 'effective amount' has a customary usage." *Id.* at 1277. "Under this usage, the term would mean 'the amount of Lewis acid inhibitor that will prevent the degradation of sevoflurane by a Lewis acid." *Id.*; *see also Minn. Mining & Mfg. Co. v. Chemque, Inc.*, 303 F.3d 1294, 1299, 1304 (Fed. Cir. 2002) (affirming construction of "effective amount" to mean "a sufficient amount of the specified component to form an encapsulant having the specified properties under the specified conditions, if any").

Not surprisingly, given this well-established precedent, patent claims frequently use "effective" in this way, to mean able to perform the recited

function.[1] JMI's own U.S. patents in the field of exhaust systems use "effective to" in their claims. Appx1253 (col.4:25-26) ("a first catalyst effective to oxidize NO_x to NO_2"); Appx1263 (col.5:53-col.6:4) ("a first catalyst . . . which is effective to catalyse a shift reaction between CO and H_2O or is effective to catalyse the conversion of a reactant to generate a hydrogen enriched exhaust gas").

[1] *E.g.*, *Perricone v. Medicis Pharm. Corp.*, 432 F.3d 1368, 1373 (Fed. Cir. 2005) (claim requiring applying "a fatty acid ester of ascorbic acid effective to solubilize in the lipid-rich layers of the skin"); *Eaton Corp. v. Rockwell Int'l Corp.*, 323 F.3d 1332, 1335-36 (Fed. Cir. 2003) (claim requiring "means (26 and 34) associated with said driveline system effective to actuate said driveline system"); *In re Smith*, 458 F.2d 1389, 1390-91 (C.C.P.A. 1972) (claim requiring "pigment which is surface coated with an organic compound effective to render said pigment oilophilic"); *In re Hoeksema*, 332 F.2d 374, 376 (C.C.P.A. 1964) (claim requiring contacting two materials "in the presence of a hydrogenation catalyst effective to hydrogenate an ethenoid double bond"); *In re Tanke*, 213 F.2d 551, 553 (C.C.P.A. 1954) (claim requiring "an adjustable part effective to selectively change the angle" between other device parts); *In re Prutton*, 200 F.2d 706, 708 (C.C.P.A. 1952) (claim requiring a lubricating oil composition with "a proportion effective to retard oxidation of the composition of an inhibitor"); *In re Peterson*, 136 F.2d 755, 755 (C.C.P.A. 1943) (claim requiring "flow-retarding means effective for producing a high back-pressure"); *Saler v. Hallock*, 109 F.2d 254, 255 (C.C.P.A. 1940) (claim requiring handle "effective to transmit flexing movement to the grid structure"); *Union Switch & Signal Co. v. Louisville Frog, Switch & Signal Co.*, 73 F.2d 550, 551 (6th Cir. 1934) (claim requiring "means effective . . . for placing the winding of such magnet on short circuit").

2. Functional terms such as "effective" cover compositions that can perform the recited function and do not require a minimum level of function

It also is a longstanding, well-established principle that functional limitations need not recite a minimum amount of function. Over fifty years ago, Judge Rich referred to functional limitations that do not specify a minimum amount of function as "so-called 'functional' definitions of uncritical amount." *In re Caldwell*, 319 F.2d 254, 258 (C.C.P.A. 1963) (emphasis omitted). He explained that "such definitions are not only common but have been expressly approved in many cases." *Id.* (collecting decisions).

Rather than requiring functional limitations to specify a minimum amount of function, the rule is that, "[b]y its own literal terms, a claim employing such language covers any and all embodiments which perform the recited function." *Swinehart*, 439 F.2d at 213. That rule is an application of the general claim construction principle that "[i]n the absence of modifiers, general descriptive terms are typically construed as having their full meaning." *Innova/Pure Water, Inc. v. Safari Water Filtration Sys.*, 381 F.3d 1111, 1118 (Fed. Cir. 2004); *see CCS Fitness, Inc. v. Brunswick Corp.*, 288 F.3d 1359, 1366 (Fed. Cir. 2002) ("If an apparatus claim recites a general structure without limiting that structure to a specific subset of structures, we will generally construe the term to cover all

known types of that structure that the patent disclosure supports." (quotation marks and brackets omitted)).

For example, in *Hill-Rom*, the Court refused to limit the scope of the functional claim term "datalink." 755 F.3d at 1371-75. The Court explained that "datalink" was defined by its function and that the "plain and ordinary meaning of datalink at the relevant time is a connection that carries data." *Id.* at 1374. The Court held that "datalink" could not be limited to a wired connection because "wireless datalinks were known at the time the patent was filed." *Id.* Because "one of skill in the art at the relevant time would understand that datalinks can be both wired and wireless, then the patentee is entitled to the full range of that claim term." *Id.* at 1375. The Court thus construed "datalink" in "functional terms" as "any link over which data is transferred and can be wired or wireless." *Id.* at 1374-75.

The principle that functional limitations cover "any and all embodiments which perform the recited function," *Swinehart*, 439 F.2d at 213, applies to the functional term "effective." "Effective" consistently has been interpreted as including any known component that effects (i.e., performs or produces) the recited function, without limiting claims to some minimum level of function.

For example, in *In re Caldwell*, the claims covered a method of stimulating growth in animals by feeding animals "rations supplying an effective amount of

aspirin for growth stimulation." 319 F.2d at 255. Although the basis for the Patent Office's rejection of the claims was obviousness, the Solicitor argued on appeal that the claims also were indefinite. *Id.* at 257-58. In rejecting that argument, Judge Rich explained that the use of functional terminology in claims had been "expressly approved." *Id.* at 258. There, the point of novelty in the claims was "the use of aspirin for growth promotion in named animals, not the amount used, which may be from the least effective amount to the amount beyond which no further beneficial effect is observed." *Id.* (emphasis omitted). He further explained: "'Effective amount' admirably states what is to be derived from the disclosure of the specification as to amount and we can see nothing 'critical' about the amount in determining the existence of patentable invention." *Id.*

This Court reached a similar conclusion in *Geneva Pharmaceuticals, Inc. v. GlaxoSmithKline PLC*, giving the claim term "effective" the full scope of its ordinary meaning. 349 F.3d 1373, 1383-84 (Fed. Cir. 2003). The claim limitation at issue there was "synergistically effective amount of clavulanic acid." *Id.* at 1383. The district court had found this term ambiguous and had relied on a disclosure in the specification to construe it to mean 50 mg to 500 mg. *Id.* This Court disagreed. As the Court explained, "[b]y its terms, a 'synergistically effective amount' is a functional limitation." *Id.* at 1384. And "a functional limitation covers all embodiments performing the recited function." *Id.* (citing

Swinehart, 439 F.2d at 213). "Thus, this claim term should not be limited to the disclosed range of 50 mg to 500 mg but instead should encompass any dosage amount that can achieve therapeutic synergy." *Id.*; *see id.* ("The term 'synergistically effective amount' must mean any amount that is synergistic against any bacteria."); *id.* ("[O]nce a particular amount yields synergy under any circumstance, that amount is 'synergistically effective.'"). Having interpreted the claim broadly according to its plain language, the Court ultimately held it invalid for nonstatutory double patenting. *Id.*[2]

While the Court in *Geneva* observed that "'effective amount' is a common and generally acceptable term for pharmaceutical claims," *id.* at 1383, the Court's rationale was not limited to pharmaceutical patents. The Court construed the limitation according to the general rule that applies to all functional limitations, including outside the pharmaceutical context—that functional limitations cover all embodiments performing the recited function. *Id.* at 1384 (citing *Swinehart*, 439 F.2d at 213). The "effective amount" of the chemical compounds which formed the pharmaceutical compositions in *Geneva* was understood by those of skill in

[2] The Court rejected the patent owner's argument that the scope of the claims depended on whether "a given antibiotic, bacteria, and disease combination provides no synergy," concluding that limiting the claims depending on the bacteria would render the claims indefinite. *Id.* Ironically, the type of "operating conditions" limitations that the district court and JMI seek to require here could create similar concerns.

that art, just as the chemical compounds that are "effective to catalyze" in the '185 patent's claims would have been understood in the art of exhaust systems.

In *Abbott*, this Court again construed "effective" as having the full scope of its ordinary meaning. 334 F.3d at 1277-80. The district court had construed "effective amount" to mean "amounts above 131 ppm of water." *Id.* at 1277. But this Court held that "[b]ecause the patentee did not deviate from the accustomed meaning of the disputed claim term, the term 'effective amount' is construed in view of its ordinary and customary meaning." *Id.* at 1278. The Court thus construed "effective amount" as not limited to any particular amount but rather as the amount "needed" to perform the recited function. *Id.*

Similarly, in *Innova*, the Court held that "operatively"—a term synonymous with "effectively"—receives the full claimed scope. The Court explained that, "subject to any clear and unmistakable disavowal of claim scope, the term 'operatively connected' takes the full breadth of its ordinary meaning." *Innova*, 381 F.3d at 1120. It further explained that the term generally "means the claimed components must be connected in a way to perform a designated function." *Id.* at 1118. Thus, it held that the claimed components were "operatively connected" whenever they are "arranged in a manner *capable of* performing" the recited function. *Id.* at 1120 (emphasis added).

3. The limitations should be given their plain meaning: material compositions effective for catalyzing SCR of NO_x and ammonia oxidation, as understood in the art of exhaust systems

This Court's well-settled precedent requires reversal of the indefiniteness ruling here. The claims of the '185 patent use "effective" consistent with its ordinary meaning, which is to effect or produce a desired result. *See supra* Parts I.B.1 and I.B.2. Thus, a "material composition A effective for catalyzing NH_3 oxidation" (Appx29 (col.19:46-47)) is a material that can catalyze ammonia oxidation. And a "material composition B effective to catalyze selective catalytic reduction (SCR) of NO_x" (Appx29 (col.19:51-52)) is a material that can catalyze SCR of NO_x. *See Swinehart*, 439 F.2d at 213.

The claims also must be interpreted within the context of exhaust systems because claim terms carry the meaning that "a person of skill *in the art in question*" would give them. *Phillips v. AWH Corp.*, 415 F.3d 1303, 1312-13 (Fed. Cir. 2005) (en banc) (emphasis added); *see also Vederi, LLC v. Google, Inc.*, 744 F.3d 1376, 1382-83 (Fed. Cir. 2014) (reversing district court's claim construction that was based on a technical meaning from a different art). The claims here explicitly identify the relevant art: "[a] catalyst system for treating an exhaust gas stream." Appx29 (col.19:40-41). The specification likewise identifies the technical field as "catalysts, methods for their manufacture, and methods of treating emissions in an exhaust system." Appx20 (col.1:6-8, 20-23).

Accordingly, the district court should have adopted BASF's proposed constructions (Appx84-85), which properly give each claim term "the full breadth of its ordinary meaning." *Innova*, 381 F.3d at 1120; *see supra* Part I.B.2. The "material composition A" limitation thus should be construed as "a material composition A effective for catalyzing ammonia oxidation as understood in the art of exhaust systems." Appx84. And the "material composition B" limitation should be construed as "a material composition B effective to catalyze selective catalytic reduction (SCR) of NO_x as understood in the art of exhaust systems." Appx85.

Instead of giving the claims these plain meanings, the district court held them indefinite. Appx5. The linchpin of its reasoning was that they do not "recite a minimum level of function needed to meet this 'effective' limitation nor a particular measurement method to determine whether a composition is 'effective' enough to fall within the claims." Appx5. But the lack of a limitation to some "minimum level of function" (Appx5) does not render the claims indefinite; it just means that no minimum level of function is required. *Hill-Rom*, 755 F.3d at 1375; *Innova*, 381 F.3d at 1120; *Geneva*, 349 F.3d at 1384; *Abbott*, 334 F.3d at 1278; *Caldwell*, 319 F.2d at 258. And because no minimum level of function is required, there is no need to specify any "particular measurement method." Appx5.

For similar reasons, the district court's observation in a footnote (Appx5 n.10) that "'a practically limitless number of materials' exist that would 'catalyze SCR of NO_x, even within the normal operating conditions of an exhaust aftertreatment system'" is beside the point. "[B]readth is not indefiniteness." *SmithKline Beecham Corp. v. Apotex Corp.*, 403 F.3d 1331, 1341 (Fed. Cir. 2005) (quoting *In re Gardner*, 427 F.2d 786, 788 (C.C.P.A. 1970)); *see also Swinehart*, 439 F.2d at 213 ("'Functional' terminology may render a claim quite broad.").

Indeed, the breadth of the "material composition" limitations is consistent with the fact that those limitations, in isolation, are not the novelty of the invention and play a limited role in defining the scope of the claims. *See Caldwell*, 319 F.2d at 258 ("'Effective amount' admirably states what is to be derived from the disclosure of the specification as to amount and we can see nothing 'critical' about the amount in determining the existence of patentable invention."). The inventors did not develop or discover new catalyst materials; they developed a novel architecture for arranging catalysts on a substrate to convert NO_x and excess ammonia in the exhaust stream into harmless compounds. This architecture—not the particular choice among catalysts—increases the conversion of pollutants to harmless nitrogen gas rather than to other, harmful byproducts. Appx16 (FIG. 7), Appx26-27 (col.13:61-col.15:2, TABLE 1). It is this architecture that circumscribes the scope of the claims. Thus, although any SCR catalyst and

ammonia oxidation catalyst can be used, the catalysts must be arranged in the architecture disclosed and claimed in the '185 patent to infringe.

C. The Intrinsic Evidence Establishes That An Ordinarily Skilled Artisan Would Understand The Scope Of The Claims With Reasonable Certainty

Under the correct construction of the material composition limitations, the intrinsic record—including the extensive disclosures in the specification that the district court did not discuss—demonstrates that a person of ordinary skill in the art would understand the claims' scope with reasonable certainty.

1. The claims encompass well-known materials for performing clearly identified functions

Claims need only be worded so as to apprise ordinarily skilled artisans what is claimed and what is still open to the public. *Nautilus*, 134 S. Ct. at 2129-30. No magic language is required. The "certainty which the law requires in patents is not greater than is reasonable, having regard to their subject-matter." *Id.* at 2129 (quoting *Minerals Separation, Ltd. v. Hyde*, 242 U.S. 261, 270 (1916)). "[W]hen a claim limitation is defined in purely functional terms, a determination of whether the limitation is sufficiently definite is highly dependent on context (*e.g.*, the disclosure in the specification and the knowledge of a person of ordinary skill in the relevant art area)." *Biosig*, 783 F.3d at 1378 (quotation marks and citation omitted). This standard does not require that a person of skill in the art would be able to list every embodiment covered by the invention. Indeed, even if some

experimentation is necessary to determine the scope of the claims, that does not render the claims indefinite. *Enzo*, 599 F.3d at 1336.

For example, in *Cox*, this Court held a functional limitation not indefinite because the patent identified the function to be performed and the specification provided an embodiment and gave details about how it functions. *Cox*, 2016 WL 5335038, at *5. One of the claims at issue, claim 1, required a "method of operating a *processing system*," under which the processing system must perform several functions. *Id.* at *2. The Court explained that "processing system" was not indefinite because the patent identifies with sufficient clarity the functions that the processing system performs—for example, that it "process[es] the signaling message to select a network code." *Id.* at *5 (alteration in *Cox*). The specification also discloses an embodiment of the processing system—a communications control processor—and describes how the communications control processor selects the network code. *Id.* at *1, *5. The Court held that these disclosures were "sufficiently detailed such that, reading claim 1 in light of the specification, a person of ordinary skill in the art would understand claim 1's requirement" with reasonable certainty. *Id.* at *5; *see also Biosig*, 783 F.3d at 1382-83 (holding claims not indefinite because the "patent's claim language, specification, and the figures" in the patent were enough to "provide sufficient clarity to skilled artisans" (quotation marks and citation omitted)).

The claims here, viewed in light of the specification, readily satisfy the reasonable certainty standard. The claims identify the functions that the claimed material compositions must perform—i.e., "catalyzing NH_3 oxidation" and catalyzing "selective catalytic reduction (SCR) of NO_x." Appx29 (col.19:46-47, col.19:51-52). The specification expressly defines "SCR function" as a "chemical process in which NO_x and NH_3 are combined to produce preferably N_2." Appx22 (col.5:33-38). And it defines "NH_3 oxidation function" as "a process in which NH_3 is reacted with oxygen to produce NO, NO_2, N_2O, or preferably N_2." Appx22 (col.5:40-47). The specification also gives an exact chemical equation for each reaction. Appx22 (col.5:35, 44). The equation for SCR is "$4NO_x + 4NH_3 + (3-2x)O_2 \rightarrow 4N_2 + 6NH_2O$." Appx22 (col.5:33-36). And the equation for ammonia oxidation is "$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$." Appx22 (col.5:40-44).

The specification also makes clear that materials effective for catalyzing SCR of NO_x and ammonia oxidation already were known to persons of skill in the art before the filing date of the invention. It refers to these materials as "SCR catalysts" and "ammonia oxidation catalysts," respectively. Appx20-28 (col.1:30-34, col.1:50-52, col.1:57-58, col.5:38-40, col.5:47-49, col.6:48-55, col.8:4-10, col.8:11-14, col.8:37-41, col.10:56-61, col.11:9-20, col.11:65-col.12:3, col.12:13-18, Table 1, col.18:23-26) (also referring to "ammonia SCR catalyst" or "SCR composition"/"component" and "AMOX catalyst" or "NH_3 oxidation

composition"/"component"). The Background section explains that "SCR catalyst materials" were already in use in engine exhaust systems. Appx20 (col.1:31-40). It describes the continuing problem of "[a]mmonia slip from the ammonia SCR catalyst." Appx20 (col.1:41-48). And it introduces a system using another known catalyst—an ammonia oxidation catalyst—"to eliminate the ammonia before it can pass into the tailpipe." Appx20 (col.1:49-58). Because SCR catalysts and ammonia oxidation catalysts were well known in the art, the specification "need not explain every detail" about these catalysts to avoid indefiniteness. *See Wellman, Inc. v. Eastman Chem. Co.*, 642 F.3d 1355, 1367 (Fed. Cir. 2011).

2. The specification provides numerous examples of the claimed materials and reinforces the claims' clear meaning

The above details are more than sufficient to provide persons of skill in the art reasonable certainty regarding the scope of the claims. Yet the specification goes further and provides even more details. As discussed below, the specification gives a general description of SCR catalysts and ammonia oxidation catalysts, as well as numerous examples of such catalysts. In view of these disclosures, a person of skill in the art would understand the scope of the "material composition" limitations.

With respect to "material composition A effective for catalyzing NH_3 oxidation," the Summary section of the specification provides a general description that it "comprises a precious metal component dispersed on support particles."

Appx20 (col.2:29-30). The specification also provides lists of exemplary support particles and precious metals. It explains that the "support particles may comprise a refractory metal oxide containing alumina, silica, zirconia, titania, ceria, and physical mixtures or combinations thereof, including atomically doped combinations." Appx20 (col.2:31-34). And the precious metal component may contain "ruthenium, rhodium, iridium, palladium, platinum, silver, or gold and physical mixtures or chemical combinations thereof, including atomically doped combinations." Appx20 (col.2:34-39); *see also* Appx29 (col.20:29-41) (dependent claims 14, 15, and 16).

The specification also includes a section titled "NH_3 Oxidation Composition" that provides additional details about the chemical components and structure of materials effective for catalyzing ammonia oxidation. Appx23 (col.8:3-56). For example, it explains that the "refractory metal oxide may contain a mixed oxide such as silica-alumina, amorphous or crystalline aluminosilicates, alumina-zirconia, alumina-lanthana, alumina-chromia, alumina-baria, alumina-ceria, and the like." Appx23 (col.8:30-34). And it identifies a specific example in which the precious metal is platinum on a high surface area γ-alumina support. Appx23 (col.8:19-21, col.8:34-36).

With respect to "material composition B effective to catalyze selective catalytic reduction (SCR) of NO_x," the specification describes a general description

of crystal-framework types that can be used and metals that can be distributed on or within the framework. The Summary section states that "material composition B" may contain "a zeolitic or non-zeolitic molecular sieve." Appx20 (col.2:52-53). The "molecular sieve can be an aluminosilicate molecular sieve having the [*sic*] one of the crystal framework types FAU, MFI, MOR, BEA, as per the designations in the Database of Zeolite Structures published by the International Zeolite Association (IZA)." Appx20 (col.2:53-58). Additionally, the molecular sieve may contain "a metal from one of the groups VB, VIB, VIIB, VIIIB, IB, or IIB of the periodic table distributed on or within the molecular sieve, the metal being present in an amount between 0.1% and 10% by wt. of the molecular sieve." Appx20-21 (col.2:64-col.3:1); *see also* Appx29 (col.20:6-8, col.20:12-24) (dependent claims 6, 8, 9, 10, and 11).

The specification also includes a section titled "SCR Composition" that provides additional details about the framework and metals. Appx22-23 (col.6:47-col.8:2). For example, it explains that the framework structures may be "chabazite, faujasite, zeolite Y, ultrastable zeolite Y, beta zeolite, mordenite, silicalite, zeolite X, and ZSM-5." Appx23 (col.7:15-18). The specification also explains that the metals distributed onto the framework "may be in one of several forms, including, but not limited to, zerovalent metal atoms or clusters, isolated cations, mononuclear or polynuclear oxycations, or as extended metal oxides." Appx22

(col.6:62-65). And the metals may include "iron, copper, and mixtures or combinations thereof." Appx22 (col.6:65-67).

This extensive, detailed discussion in the specification is more than enough to allow persons of ordinary skill to understand with reasonable certainty the "material composition" limitations of the '185 patent. *See Cox*, 2016 WL 5335038, at *5 (holding that intrinsic evidence alone established that claim was not indefinite); *SimpleAir, Inc. v. Sony Ericsson Mobile Comm'cns AB*, 820 F.3d 419, 432 (Fed. Cir. 2016) (same); *Biosig*, 783 F.3d at 1382-84 (same); *Eidos*, 779 F.3d at 1364-65 (same). Based on the ordinary meaning of "effective" and the disclosures in the intrinsic record, this Court can and should reverse the district court's indefiniteness judgment as a matter of law. *See Cox*, 2016 WL 5335038, at *3 ("If indefiniteness can be determined based solely on intrinsic evidence, our review is de novo."). The Court then need not consider the extrinsic evidence, and the case should be remanded for proceedings on infringement.

II. THE EXTRINSIC EVIDENCE LIKEWISE COMPELS THE CONCLUSION THAT JMI DID NOT MEET ITS BURDEN OF ESTABLISHING BY CLEAR AND CONVINCING EVIDENCE THAT THE CLAIMS ARE INDEFINITE

Were this Court to consider the extrinsic evidence, it likewise compels the conclusion that a person of ordinary skill in the art would understand the scope of the claims with reasonable certainty.

A. Under the Correct Claim Construction Of The "Material Composition" Limitations, The Undisputed Extrinsic Evidence Confirms That Ordinarily Skilled Artisans Would Understand The Scope Of The Claims

Indefiniteness must be judged from the perspective of a person of ordinary skill in the art at the time of filing. *Nautilus*, 134 S. Ct. at 2128. Even when a patent fails to provide detailed intrinsic guidance (not true here, because the '185 patent does provide such guidance, *supra* Part I.C), the claims are not indefinite if one of ordinary skill in the art would understand claim scope based on background knowledge and use in the art. *Wellman*, 642 F.3d at 1367-68. Under the correct construction of the "material composition" limitations, there is no genuine dispute of material fact that the extrinsic evidence establishes such background knowledge and use here: both sides proffered expert declarations and numerous art references showing that SCR catalysts and ammonia oxidation catalysts were known to persons of skill in the art before the '185 patent's filing date. Thus, on this key point, JMI's expert's declaration supports BASF's position. His opinion that the claims were indefinite was based on a different, legally erroneous assumption: JMI's contention that the claims require a minimum level of function. But that claim construction is wrong for the reasons explained above. *See supra* Part I.B. The undisputed, material extrinsic evidence, which this Court reviews de novo (*Eidos*, 779 F.3d at 1364-65), therefore provides an

additional basis to reverse outright and remand for further proceedings on infringement.

1. Skilled artisans were familiar with materials effective for catalyzing SCR of NO_x and ammonia oxidation by the filing date

Declarations and testimony from both parties' experts, as well as numerous references in the record, show that persons of skill in the art were familiar with materials that catalyze SCR of NO_x and ammonia oxidation by the time of the '185 patent's filing. Skilled artisans thus would understand the scope of the claims.

BASF's expert, Dr. Crocker, explained that by the time of the 2008 filing date, materials that could catalyze SCR of NO_x and materials that could catalyze ammonia oxidation were well-known to persons of ordinary skill in the art. Appx1318. Consistent with the express teachings of the '185 patent (*supra* Part I.C), Dr. Crocker explained that these materials were known as ammonia oxidation or "AMOx catalysts" and "SCR catalysts." Appx1318-1319. He further explained that by the filing date, "SCR catalysts and AMOx catalysts were well-known" in the art. Appx1319.

As to SCR catalysts, Dr. Crocker explained that by 2002, engine manufacturers were using SCR catalysts for mobile applications, such as heavy-duty diesel engines. Appx317; Appx1319; Appx1373-1374. By 2008, two of the

most popular SCR catalysts for mobile applications were iron zeolite catalysts and vanadia/titania type catalysts. Appx1322.

In addition, the '185 patent cites a 2002 reference by Heck and Farrauto called *Catalytic Air Pollution Control* that discusses materials known to catalyze SCR of NO_x in heavy-duty diesel engines. Appx22 (col.5:11-13) ("Heck"). Although BASF referred to Heck in the district court as "extrinsic evidence" that had been "identifie[d]" by the specification (Appx98), the fact that Heck was discussed in the specification arguably makes it intrinsic evidence. *V-Formation, Inc. v. Benetton Grp. SPA*, 401 F.3d 1307, 1310-11 (Fed. Cir. 2005) ("This court has established that 'prior art cited in a patent or cited in the prosecution history of the patent constitutes intrinsic evidence.'" (quoting *Kumar v. Ovonic Battery Co.*, 351 F.3d 1364, 1368 (Fed. Cir. 2003))). Regardless of whether it is intrinsic or extrinsic, the specification's identification of Heck means "it can have particular value as a guide to the proper construction" of the patent. *Id.* And Heck's discussion of materials known to catalyze SCR of NO_x includes metals such as copper, iron, vanadium, and platinum dispersed or supported on zeolites or non-zeolitic materials. Appx317; Appx1372-1376. The reference even discloses that manufacturers already were commercializing SCR catalysts. Appx1376; *see also* Appx1378-1387 (2001 reference titled "Advanced Urea SCR Catalysts for Automotive Applications").

As to ammonia oxidation catalysts, Dr. Crocker explained that they also were known to persons of ordinary skill in the art and were in use by the filing date. Appx1319; *see* Appx317; Appx1321-1322; *see also* Appx1383-1384 (2001 reference stating that an "NH_3 oxidation catalyst (O-catalyst) loaded with 10 g/ft^3 Pt [i.e., platinum] was used"). Multiple scientific publications in the record discuss materials that catalyze ammonia oxidation. Appx990-1145. These references include two patents titled "Ammonia Oxidation Catalyst," an article titled "The Properties of Cobalt Oxide for Ammonia Oxidation," and an article titled "Catalytic Oxidation of Ammonia." Appx991; Appx996; Appx1008; Appx1095.

JMI's expert, Dr. Epling, submitted a declaration that confirms that SCR catalysts and ammonia oxidation catalysts for use in engine exhaust systems were known and in use by the 2008 filing date. Dr. Epling stated that between 2003 and 2005 he "worked on NO_x reduction catalysts, including lean NO_x traps and *SCR catalysts*." Appx951 (emphasis added). He worked on "integrating these catalytic systems into engine exhaust after-treatment systems." Appx951. He also stated that between 2005 and 2011, he "led a research group focused on understanding and engineering catalyst compositions to treat engine exhaust streams, including *catalysts for the SCR of NO_x*." Appx951 (emphasis added). By the filing date, he "had more than 5 years of experience designing and developing new and improved catalysts to treat emissions from diesel engines, including *catalysts for the SCR of*

NO_x." Appx952 (emphasis added). Dr. Epling's description of his own work thus demonstrates that SCR catalysts were known and in use.

Likewise, Dr. Epling confirmed that ammonia oxidation catalysts were known and used in the art of engine exhaust systems. Appx953-955. Dr. Epling had no trouble identifying materials that "would, to some measurable extent, catalyze the oxidation of ammonia if used to treat diesel engine emissions." Appx953.

Dr. Epling also explained that "[t]here are objective standards" by which a person of ordinary skill in the art could determine whether and the extent to which a given material is a catalyst under any given conditions. Appx957. "For example, scientists and engineers in this field frequently refer to the 'percent conversion' of a catalyst." Appx957. "This refers to the percent of a chosen reactant that is converted to the desired product under defined conditions that can be repeated." Appx957. He further explained how persons of ordinary skill in the art determine the percent conversion of any given material. Appx957. Dr. Epling's explanation is consistent with details in the '185 patent itself, which also describes how to measure and use percent conversion for catalyst materials. Appx26-29 (col.13:60-col.19:14; Table 1); *see also* Appx17-19 (FIGs. 8-12). His explanation thus establishes that an ordinarily skilled artisan would be able to determine through

objective standards whether a given material can catalyze SCR of NO_x or ammonia oxidation.

There thus is no dispute in the extrinsic evidence that, under the correct construction, materials effective to catalyze SCR of NO_x and ammonia oxidation were widely known and in use in the art of exhaust systems before the '185 patent's filing date, and ordinarily skilled artisans could determine whether materials can catalyze each reaction. In light of that background knowledge, a person of ordinary skill in the art would understand the scope of the patent's claims.

2. Persons of skill in the art used the same terms as the '185 patent to refer to materials effective for catalyzing SCR of NO_x and ammonia oxidation

Apart from the fact that SCR catalysts and ammonia oxidation catalysts themselves were known and in use, the limitations are sufficiently clear because the *phrases* "SCR catalyst" and "ammonia oxidation catalyst" had an established meaning and were widely used by persons skilled in the art. In *DDR Holdings, LLC v. Hotels.com, L.P.*, this Court considered the claim term "visually perceptible elements," which had been construed as "'look and feel' elements that can be seen." 773 F.3d 1245, 1259-60 (Fed. Cir. 2014). The Court held that "visually perceptible elements" provided sufficient clarity because "look and feel" "had an established meaning in the art by the relevant timeframe" and the patent used the

term consistent with its established meaning. *Id.* at 1261. In so holding, the Court pointed to the patent challenger's own advertisements that used "look and feel." *Id.* at 1260-61; *see also Ancora Techs., Inc. v. Apple, Inc.*, 744 F.3d 732, 737 (Fed. Cir. 2014) (rejecting indefiniteness challenge because patent defined claim scope using terms with "a meaning that is clear, settled, and objective in content").

As explained, the specification refers to "material composition A effective for catalyzing NH_3 oxidation" as an "ammonia oxidation catalyst" and to "material composition B effective to catalyze SCR of NO_x" as an "SCR catalyst." *See supra* Part I.C. A named inventor on the '185 patent confirmed that understanding, stating that "[m]aterial composition A was our designation for our AMOx catalyst" and "material composition B" designated an "SCR catalyst." Appx179, Appx182.

The undisputed extrinsic evidence makes clear that "SCR catalyst" and "ammonia oxidation catalyst" had established meanings. For example, the 2002 Heck reference refers to "SCR catalysts" as materials that will catalyze SCR of NO_x. Appx1374. Indeed, Dr. Epling's description of his own work on "SCR catalysts" demonstrates that he understood that term and used it for its established meaning. Appx951; *see DDR*, 773 F.3d at 1261. And multiple scientific publications in the record specifically refer to materials that catalyze ammonia oxidation as "ammonia oxidation catalysts" or variations of that phrase. Appx990-1145.

Because the '185 patent describes the scope of its claims using terms that had an established meaning in the art by the time of filing, the claims are not indefinite.

3. Under the correct claim construction, JMI's expert's declaration does not create any material dispute of fact pertinent to the indefiniteness question

No material disputes of fact would preclude this Court from deciding based on the extrinsic evidence that materials effective to catalyze SCR of NO_x and ammonia oxidation were known and understood by persons of skill in the art. As to all the facts that are pertinent to the indefiniteness inquiry under the correct claim construction of the "material composition" limitations, Dr. Epling agreed with Dr. Crocker.

Although Dr. Epling opined that a skilled artisan would not be able to determine with reasonable certainty what materials are sufficiently "effective" to catalyze SCR of NO_x or ammonia oxidation (Appx954-955), that opinion was based on the wrong claim construction. The reason Dr. Epling gave for his opinion was that the patent "provides no standard to determine whether any particular composition is *effective enough* in catalyzing SCR." Appx955 (emphasis added); *see* Appx953-954 (similar). But as discussed in Part I.B above, the "material composition A" and "material composition B" limitations include any compositions "effective" to catalyze ammonia oxidation or SCR of NO_x as

understood in the art of exhaust systems, without any limitation based on whether a material is "effective enough." Dr. Epling had no trouble identifying materials understood in the art of exhaust systems to catalyze these reactions. Appx953-956.

Dr. Epling also stated that there was uncertainty over what materials were covered by the "material composition A" and "material composition B" limitations because some materials are effective at catalyzing reactions under certain conditions but not under other conditions. Appx954-956. For example, he explained that "certain compositions having platinum can catalyze the SCR reaction, but under rather limited conditions." Appx956. "Similarly, depending on temperature, specific iron-based zeolites or copper-based zeolites may be preferred as SCR catalysts, with copper outperforming iron at low temperatures (<300C) and iron outperforming copper at the higher temperatures." Appx956. And certain copper zeolite compositions "displayed no SCR function under certain conditions within the normal range of exhaust from a diesel engine." Appx955.

That is beside the point. Whether a particular material may or may not fall within the claimed scope depending on conditions does not render claims indefinite. *Orthokinetics, Inc. v. Safety Travel Chairs, Inc.*, 806 F.2d 1565, 1575-76 (Fed. Cir. 1986). If those of ordinary skill in the art can identify the conditions and recognize whether a particular material in those conditions meets the claim

limitation, nothing more is required. *Id.* at 1576; *see also Source Search Techs., LLC v. LendingTree, LLC*, 588 F.3d 1063, 1076-77 (Fed. Cir. 2009).

Dr. Epling's own statements establish that those skilled in the art of exhaust systems can determine whether a material composition is able to catalyze SCR of NO_x or ammonia oxidation in a given set of conditions. As discussed above, he explained that persons of skill in the art use objective standards to determine whether a material can catalyze. Appx957. Dr. Epling also gave detailed examples of which materials can catalyze under which conditions. Appx954-956. BASF's expert Dr. Crocker likewise explained, "it was well-known to persons of ordinary skill in the art that the catalytic performance of certain catalysts would vary based on environmental considerations, such as temperature." Appx1319. But this "known variance in catalytic performance would not have created confusion among ones of ordinary skill in the art." Appx1319.

In short, because the undisputed extrinsic evidence established that SCR catalysts and ammonia oxidation catalysts were well known and widely used by the time of the application for the '185 patent, persons of ordinary skill in the art would understand the scope of the claims with reasonable certainty.

B. At A Minimum, The Case Should Be Remanded For Resolution Of Any Fact Dispute In The First Instance

For all the reasons in Part I, *supra*, this Court can and should determine as a matter of law that the intrinsic evidence demonstrates that an ordinarily skilled

artisan would understand the scope of the "material composition" limitations with reasonable certainty. *See Eidos*, 779 F.3d at 1364-65. Were the Court also to review the extrinsic evidence, it can and should come to the same conclusion as a matter of law for the reasons in Part II.A, *supra*. *See Eidos*, 779 F.3d at 1364-65. But were this Court to conclude that resort to the extrinsic evidence is necessary and that uncertainty exists about its meaning, the burden would fall on JMI to overcome that uncertainty and prove by clear and convincing evidence that the claims are indefinite. *See Cox*, 2016 WL 5335038, at *3 ("'Any fact critical to a holding on indefiniteness . . . must be proven by the challenger by clear and convincing evidence.'" (quoting *Intel Corp. v. VIA Techs., Inc.*, 319 F.3d 1357, 1366 (Fed. Cir. 2003)) (alteration in *Cox*)). Thus, at a minimum, vacatur of the indefiniteness ruling and a remand to the district court would be required for it to consider whether JMI can meet that high burden under the correct construction.

CONCLUSION

The judgment that the claims of the '185 patent are invalid as indefinite should be reversed, and the case should be remanded for infringement proceedings. Alternatively, and at a minimum, the invalidity judgment should be vacated and the case remanded for the district court to determine whether, under the correct construction, JMI can prove by clear and convincing evidence that a person of skill

in the art would not be able to ascertain the claims' scope with reasonable certainty.

Respectfully submitted,

Dated: October 21, 2016

/s/ Deanne E. Maynard

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IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF DELAWARE

BASF CORPORATION,	)	
	)	
Plaintiff,	)	
	)	
v.	)	Civ. No. 14-1204-SLR-SRF
	)	
JOHNSON MATTHEY INC.,	)	
	)	
Defendant.	)	

MEMORANDUM ORDER

At Wilmington this 9th day of February, 2016, having heard argument on, and having reviewed the papers submitted in connection with, the parties' proposed claim construction;

IT IS ORDERED that the disputed claim language of U.S. Patent No. 8,524,185 ("the '185 patent") shall be construed consistent with the tenets of claim construction set forth by the United States Court of Appeals for the Federal Circuit in *Phillips v. AWH Corp.*, 415 F.3d 1303 (Fed. Cir. 2005), as follows:

1. **"monolithic catalyst substrate"**[1] / **"monolithic substrate:"**[2] "Catalyst substrate formed as a single piece of material." Claim 1 recites "the system comprising: at least one monolithic catalyst substrate having an inlet end and an outlet end" (19:43), indicating that while a system may comprise more than one monolithic catalyst substrate, each substrate is a single piece of material with two ends. Overall, the

[1] Found in claim 1.

[2] Found in claims 1, 2, and 4.

language and context of the claim would be nonsensical if a monolithic substrate referred to multiple pieces of material, particularly given the identification of "an inlet end" and "an outlet end." (19:42-43) The claim describes a single piece of material coated with an undercoat washcoat layer on the outlet end and an overcoat washcoat layer over the total length of the substrate, supporting the notion of a single piece of material. Additionally, dependent claims 2 and 4 refining the substrate further indicate that it is formed as a single piece of material.

2. Turning to the specification, a "catalyst system" is defined as including "two or more chemical catalytic functions on one substrate or on more than one separate substrate." (1:64-67) Nothing in the specification, claim language, or proffered extrinsic evidence indicates that a plurality of catalytic functions cannot coexist on a single piece of material. Further, one embodiment specifies that "the substrate is a single monolithic substrate. The monolithic substrate can be a flow-through honeycomb substrate comprising a plurality of fine, substantially parallel gas flow passages extending along the longitudinal axis of the substrate." (1:11-15) Contrary to defendant's assertion, this language indicates that the patentee intended that the substrate consist of one piece of material. The specification is additionally devoid of any suggestion that a substrate could be characterized as a single unit rather than a single piece of material.

3. **"an overcoat washcoat layer coated over a total length of the monolithic substrate from the inlet end to the outlet end"**[3] **/ "an overcoat washcoat layer coated over a total length of the honeycomb substrate from the**

[3] Found in claim 1.

inlet end to the outlet end of the substrate:"[4] "A compositionally distinct material coated over a total length of the monolithic substrate from the inlet end to the outlet end" and "a compositionally distinct material coated over a total length of the honeycomb substrate from the inlet end to the outlet end of the substrate." The term "washcoat layer" is defined in the specification as consisting "of a compositionally distinct layer of material disposed on the surface of the monolithic substrate or an underlying washcoat layer." (5:10-15) The calcination process referred to in plaintiff's proposed construction does not appear in any of the claims. Rather, the concept of calcination is discussed in the patent as an option, but not strictly as a requirement for forming the washcoat layer. For instance, the specification recites "processing steps **may** include fixation by an acidic component ... or a basic component ..., chemical reduction, **or** calcination" (9:30-33) (emphasis added), and "[t]he resulting copper-containing molecular sieve **may** also be calcined to fix the copper" (10:4-5) (emphasis added). Inclusion of the word "may" indicates that the patentee intended calcination as one of several available options in forming the washcoat layer. To require calcining coatings together would improperly import claim limitations from the specification. *Superguide Corp. v. DirecTV Enterprises, Inc.*, 358 F.3d 870, 875 (Fed. Cir. 2004) ("[I]t is important not to import into a claim limitations that are not part of the claim. For example, a particular embodiment appearing in the written description may not be read into a claim when the claim language is broader than the embodiment.").[5]

---

[4] Found in claim 17.

[5] The court declines at this time to determine whether a washcoat layer requires a uniform loading across the length of the substrate.

4. **"material composition A effective for catalyzing NH3 oxidation"**[6] / **"material composition B effective to catalyze selective catalytic reduction (SCR) of NOx"**[7] / **"material composition further effective to catalyze SCR of NOx"**[8] / **"a material composition B free from precious metal effective for catalyzing selective catalytic reduction (SCR) of NOx:"**[9] Indefinite under 35 U.S.C. § 112, ¶ 2. The definiteness requirement is rooted in § 112, ¶ 2, which provides that "the specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the applicant regards as his invention." "A determination of claim indefiniteness is a legal conclusion that is drawn from the court's performance of its duty as the construer of patent claims." *Personalized Media Comm., LLC v. Int'l Trade Com'n*, 161 F.3d 696, 705 (Fed. Cir. 1998). Reiterating the public notice function of patents, the Supreme Court recently explained that "a patent must be precise enough to afford clear notice of what is claimed, thereby 'appris[ing] the public of what is still open to them.' " Nautilus, Inc. v. Biosig Instruments, Inc., —— U.S. ——, 134 S.Ct. 2120, 2129 (2014) (citations omitted). In balancing the need for clarity with the inherent limitations of the English language, 35 U.S.C. § 112, ¶ 2 requires "that a patent's claims, viewed in light of the specification and prosecution history, inform those skilled in the art about the scope of the invention with reasonable certainty." *Id.*

5. Claim 1 recites an undercoat washcoat layer containing a "material composition A effective for catalyzing NH3 oxidation" and an overcoat washcoat layer

---

[6] Found in claim 1.

[7] Found in claim 1.

[8] Found in claim 5.

[9] Found in claim 17.

containing "a material composition B effective to catalyze selective catalytic reduction (SCR) of NOx." (9:41-47) Claim 5 recites "a material composition further effective to catalyze SCR of NOx." (20:3-5) Claim 17 recites an overcoat washcoat layer containing "a material composition B free from precious metal effective for catalyzing selective catalytic reduction (SCR) of NOx." (20:42-62) Each claim fails to limit the "material composition A" or the "material composition B" to any specific materials. Rather than explicitly defining the material compositions, the claims utilize functional language, specifically "effective," to purportedly define them. In other words, the claims recite a performance property the composition must display, rather than its actual composition. Moreover, none of the claims recite a minimum level of function needed to meet this "effective" limitation nor a particular measurement method to determine whether a composition is "effective" enough to fall within the claims.[10] Without such information, a person of ordinary skill in the art could not determine which materials are within the "material composition A" or "material composition B" limitation, and which are not. *Nautilus*, 134 S. Ct. at 2129 ("a patent must be precise enough to afford clear notice of what is claimed, thereby appris[ing] the public of what is still open to them"). Lacking sufficient detail defining "material composition A" and "material composition B," the court concludes that the disputed limitations are not "precise enough to afford clear notice of what is claimed" and do not provide reasonable certainty as to the scope of the invention. *Id.*

[10] The court additionally notes that "a practically limitless number of materials" exist that would "catalyze SCR of NOx, even within the normal operating conditions of an exhaust aftertreatment system," indicating that the claims, as written, fail to sufficiently identify the material compositions. (D.I. 102 at ¶ 22)

6. The court has provided a construction in quotes for the claim limitations at issue. The parties are expected to present the claim construction to the jury consistently with any explanation or clarification herein provided by the court, even if such language is not included within the quotes.

United States District Judge

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

BASF CORPORATION,	)	
	)	
Plaintiff,	)	
	)	
v.	)	C.A. No. 14-1204 (SLR)(SRF)
	)	
JOHNSON MATTHEY INC.,	)	
	)	
Defendant.	)	

[PROPOSED] JUDGMENT IN A CIVIL CASE

WHEREAS on February 9, 2016, the Court issued a Memorandum Order construing the disputed terms of U.S. Patent No. 8,524,185 (the "'185 patent") (D.I. 131); and

WHEREAS each and every claim of the '185 patent includes one or more limitations that the Court concluded were indefinite, and as a result, each and every claim of the '185 patent stands invalid as indefinite under the Court's February 9, 2016 Memorandum Order;

IT IS ORDERED AND ADJUDGED that judgment of invalidity of the claims of U.S. Patent No. 8,524,185 be and is hereby entered in favor of Defendant Johnson Matthey Inc. and against Plaintiff BASF Corporation in Civil Action No. 14-1204-SLR-SRF.

The parties expressly reserve their rights to appeal from this invalidity judgment, and from any and all other orders and rulings adverse to them, including rulings in the Court's Memorandum Order of February 9, 2016.

This is a final, appealable judgment.

SO ORDERED this 29th day of February, 2016.

UNITED STATES DISTRICT JUDGE

9884058

US008524185B2

(12) **United States Patent**
Caudle et al.

(10) **Patent No.: US 8,524,185 B2**
(45) **Date of Patent: Sep. 3, 2013**

(54) **INTEGRATED SCR AND AMOX CATALYST SYSTEMS**

(75) Inventors: **Matthew Tyler Caudle**, Hamilton, NJ (US); **Martin Dieterle**, Jersey City, NJ (US); **Scott E. Buzby**, Burlington Township, NJ (US)

(73) Assignee: **BASF Corporation**, Florham Park, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 770 days.

(21) Appl. No.: **12/263,871**

(22) Filed: **Nov. 3, 2008**

(65) **Prior Publication Data**

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(51) **Int. Cl.**
C01B 31/30 (2006.01)
B01D 47/00 (2006.01)
B01D 46/04 (2006.01)

(52) **U.S. Cl.**
USPC **423/237**; 423/210; 423/212; 423/243.12

(58) **Field of Classification Search**
None
See application file for complete search history.

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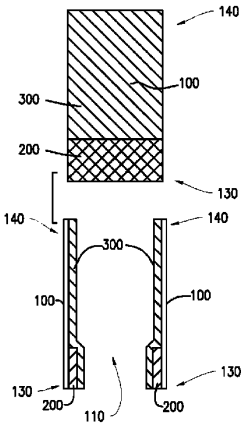
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Primary Examiner — Melvin Curtis Mayes
Assistant Examiner — Sheng H Davis
(74) *Attorney, Agent, or Firm* — Melanie L. Brown

(57) **ABSTRACT**

Catalysts, methods of preparing catalyst, and methods for treating exhaust gas streams are described. In one or more embodiments, a catalyst system includes an upstream zone effective to catalyze the conversion of a mixture of NO_x and NH_3 to N_2, and a downstream zone effective for the conversion of ammonia to N_2 in the presence or absence of NO_x. In an embodiment, a method for preparing a catalyst system includes: first coating one end of a substrate along at least 5% of its length with an undercoat washcoat layer containing a material composition effective to catalyze the removal of ammonia; second coating with an overcoat layer containing a material composition effective to catalyze the conversion of a mixture of NO_x and NH_3 to N_2. A method for treating the exhaust gas stream is provided, which includes injecting ammonia or an ammonia precursor into an exhaust gas stream of a vehicle, passing the engine exhaust gas stream containing NO_x and NH_3 through the upstream zone of a catalyst system to remove NO_x and then passing the exhaust gas stream through the downstream zone of the catalyst system to remove NH_3, as well as other oxidizable species such as hydrocarbons and CO.

17 Claims, 10 Drawing Sheets



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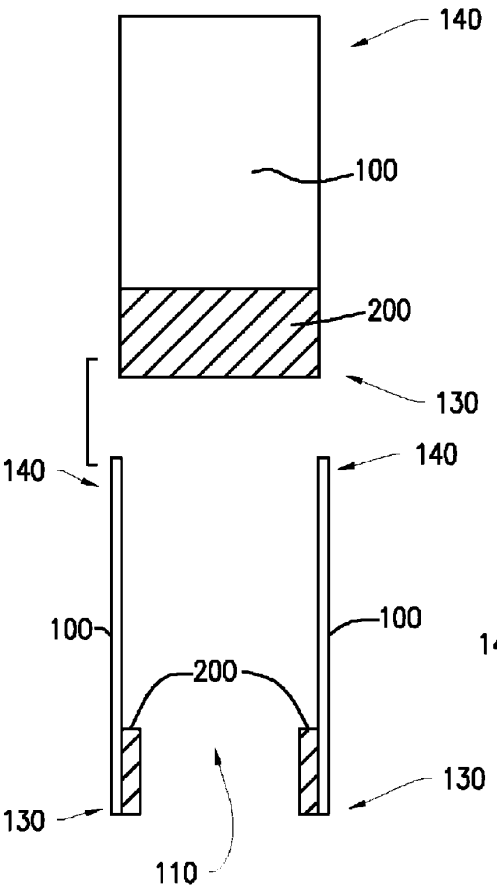

140
100
200
130
140
140
100
100
200
130
130
110

FIG. 1(a)

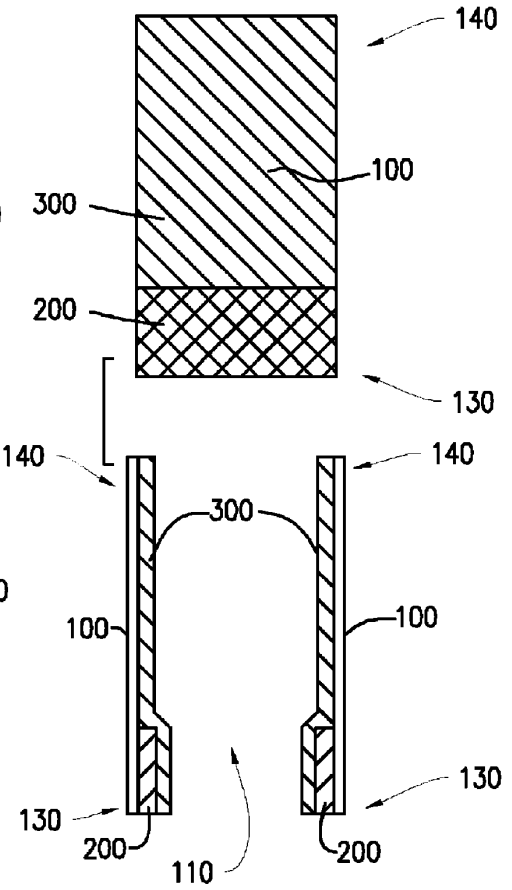

140
100
300
200
130
140
140
300
100
100
130
130
200
110
200

FIG. 1(b)

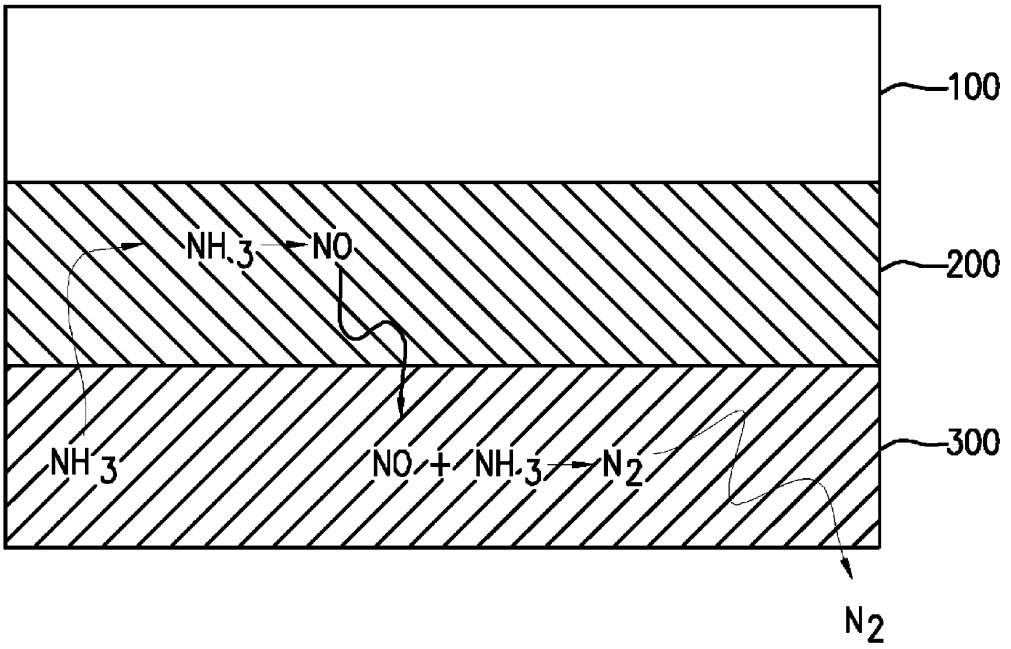


FIG. 2

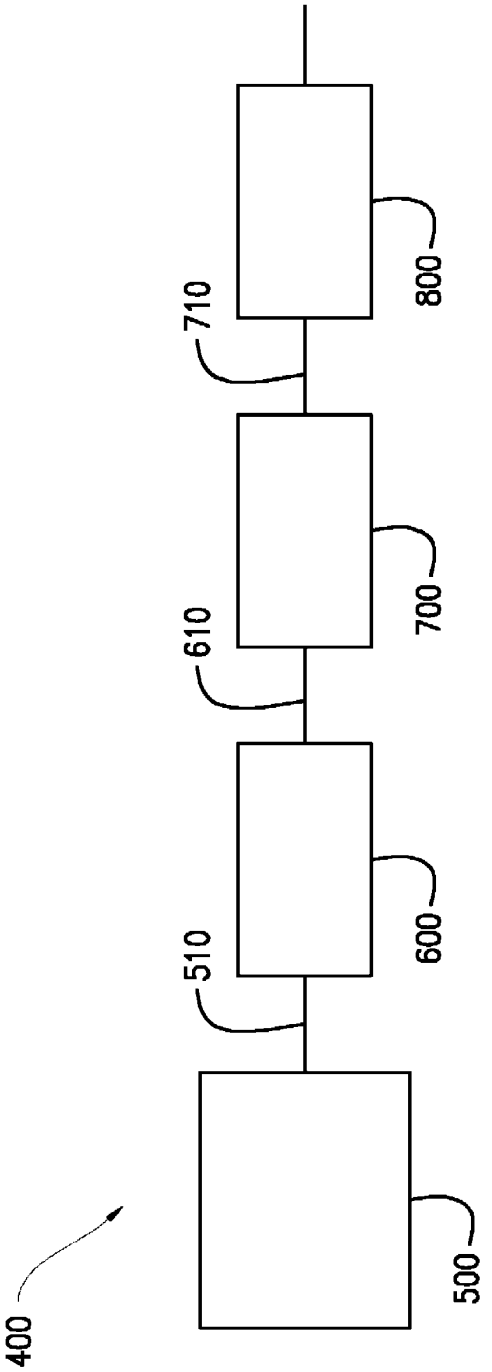


FIG. 3

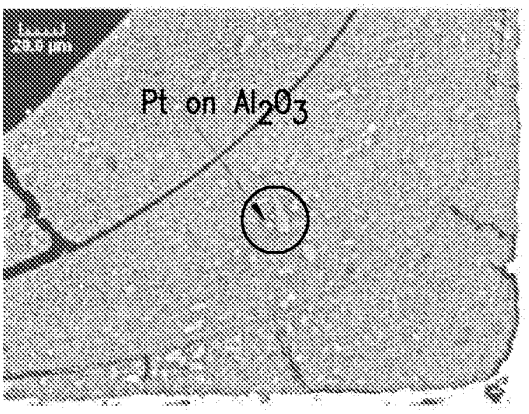


FIG. 4(a)

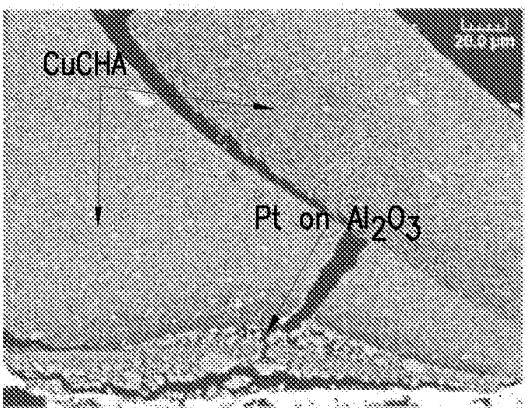


FIG. 4(b)

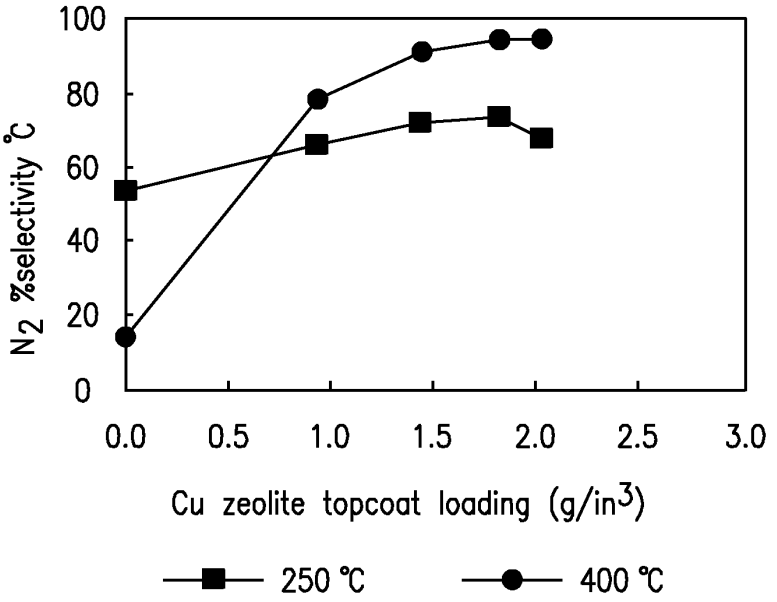

100
80
60
40
20
0
N_2 %selectivity ℃
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Cu zeolite topcoat loading (g/in^3)
250 ℃
400 ℃

FIG. 5(a)

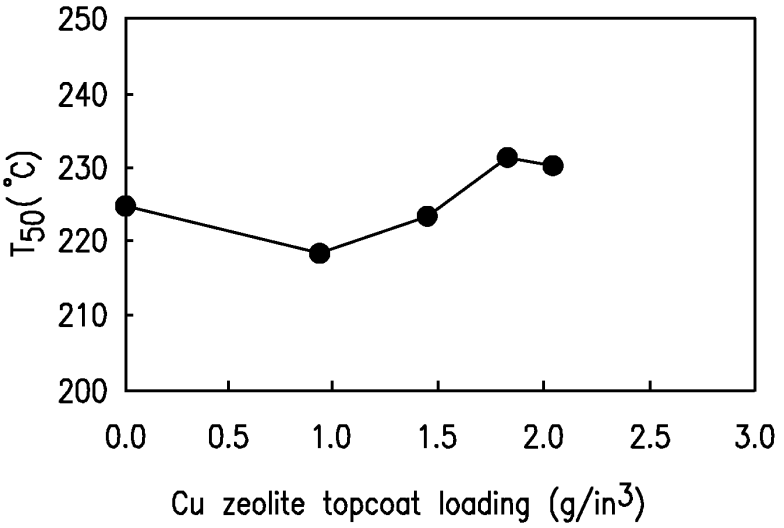

250
240
230
220
210
200
T_{50}(℃)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Cu zeolite topcoat loading (g/in^3)

FIG. 5(b)

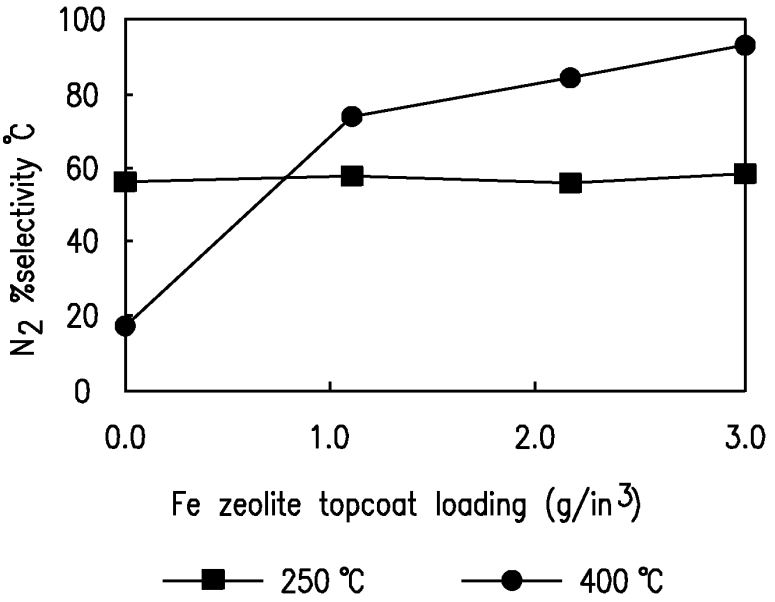

100
80
60
40
20
0
N_2 %selectivity ℃
0.0
1.0
2.0
3.0
Fe zeolite topcoat loading (g/in^3)
250 ℃
400 ℃

FIG. 6(a)

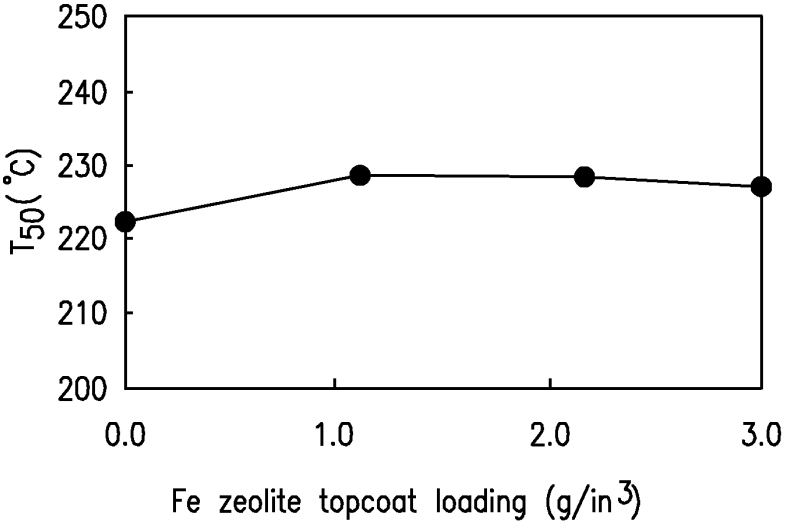

250
240
230
220
210
200
T_{50}(℃)
0.0
1.0
2.0
3.0
Fe zeolite topcoat loading (g/in^3)

FIG. 6(b)

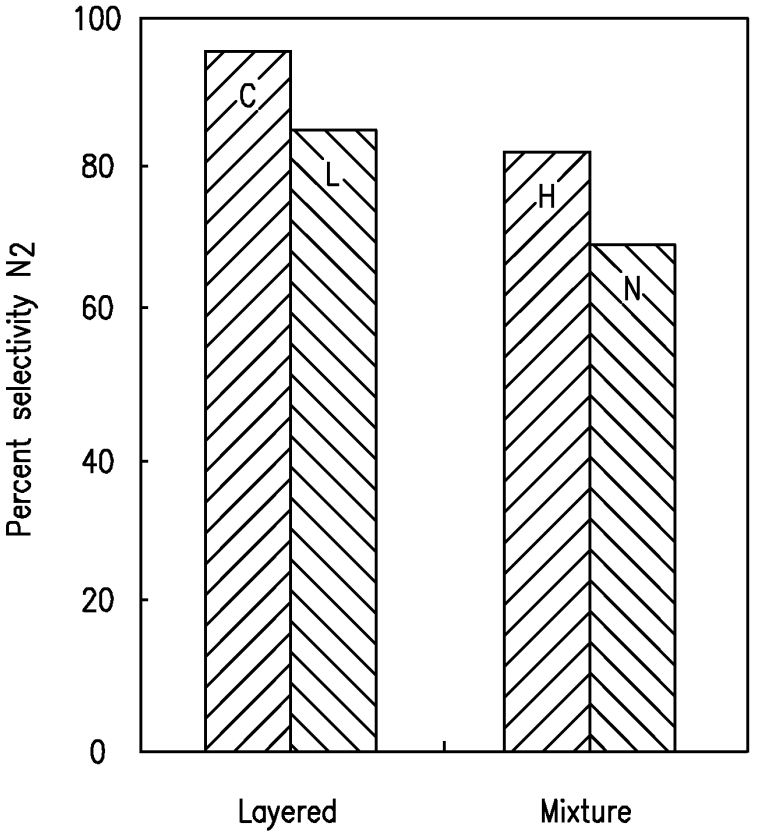

100
80
60
40
20
0
Percent selectivity N2
C
L
H
N
Layered
Mixture

FIG. 7

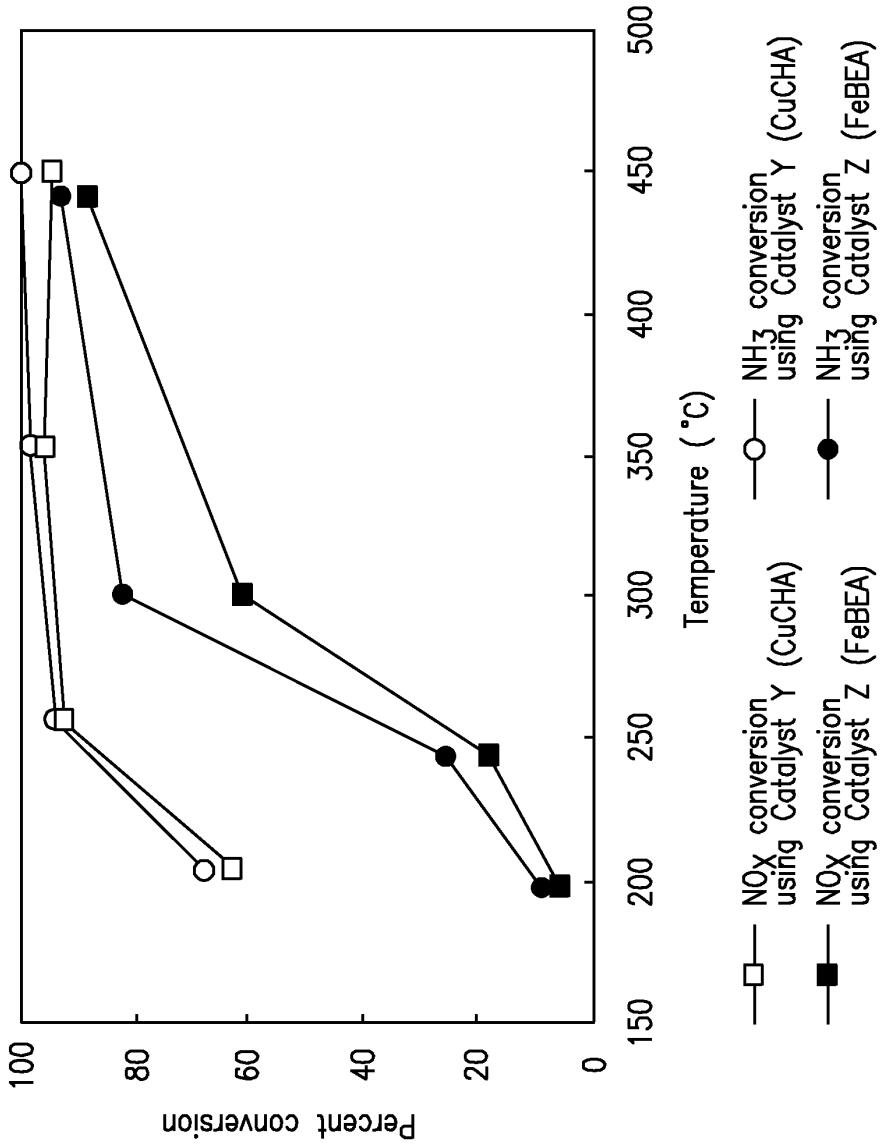

Percent conversion
100
80
60
40
20
0
150
200
250
300
350
400
450
500
Temperature (°C)
NOx conversion using Catalyst Y (CuCHA)
NOx conversion using Catalyst Z (FeBEA)
NH3 conversion using Catalyst Y (CuCHA)
NH3 conversion using Catalyst Z (FeBEA)

FIG. 8

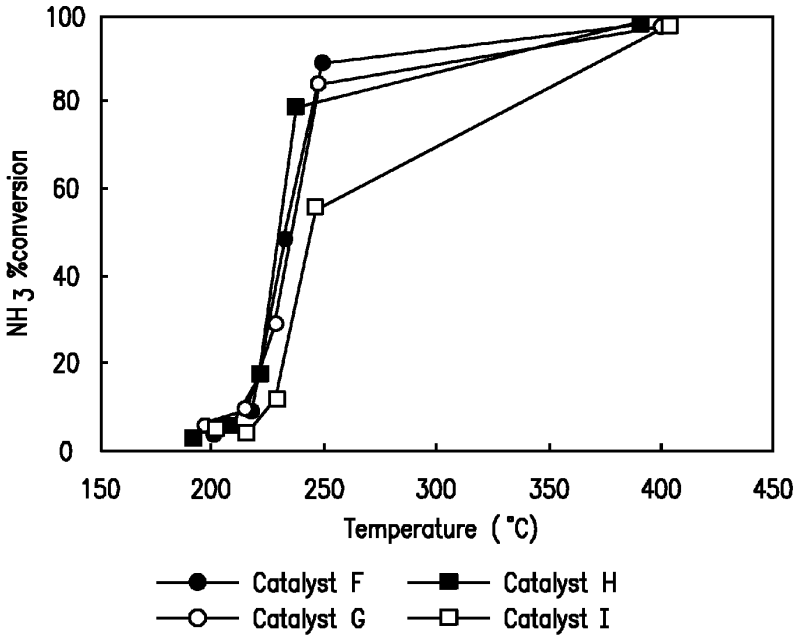

100
80
60
40
20
0
NH 3 %conversion
150
200
250
300
350
400
450
Temperature (°C)
Catalyst F
Catalyst H
Catalyst G
Catalyst I

FIG. 9

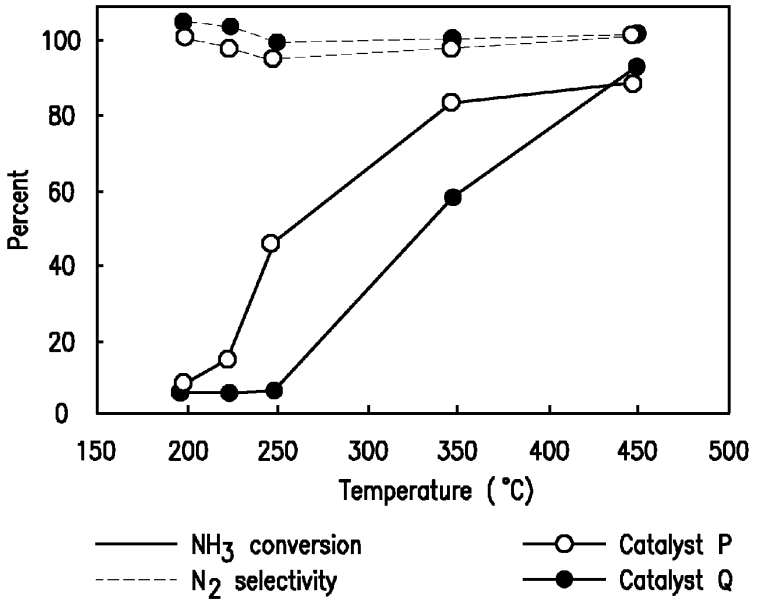

100
80
60
40
20
0
Percent
150
200
250
300
350
400
450
500
Temperature (°C)
NH3 conversion
N2 selectivity
Catalyst P
Catalyst Q

FIG. 10

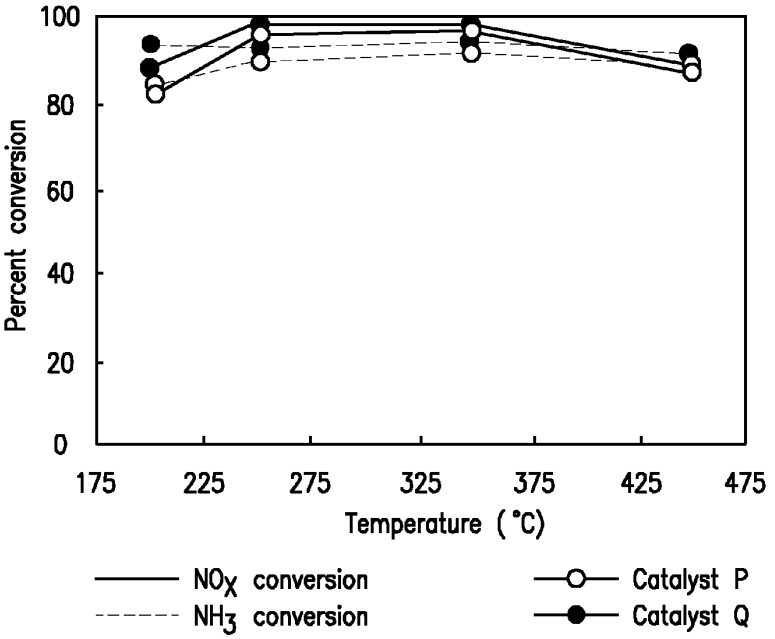

100
80
60
40
20
0
Percent conversion
175
225
275
325
375
425
475
Temperature (°C)
NOX conversion
NH3 conversion
Catalyst P
Catalyst Q

FIG. 11

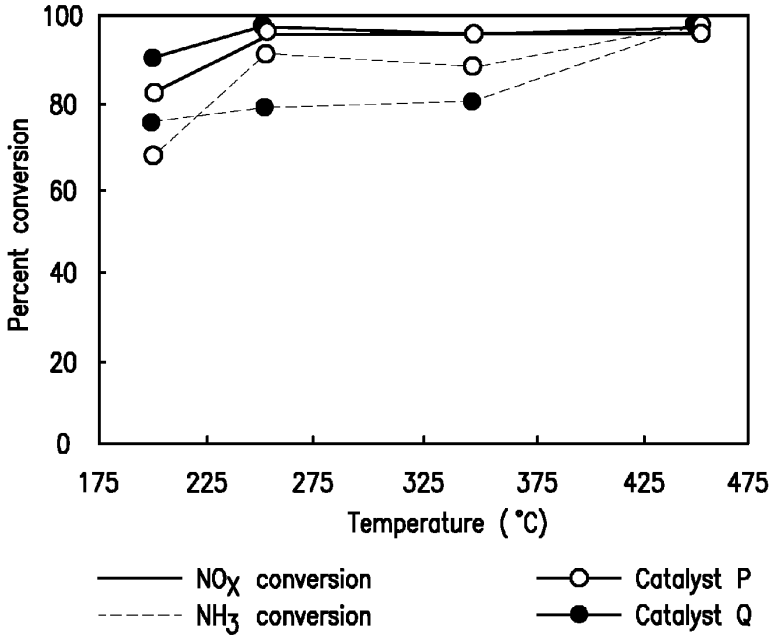

100
80
60
40
20
0
Percent conversion
175
225
275
325
375
425
475
Temperature (°C)
NOX conversion
NH3 conversion
Catalyst P
Catalyst Q

FIG. 12

INTEGRATED SCR AND AMOX CATALYST SYSTEMS

TECHNICAL FIELD

The invention pertains to catalysts, methods for their manufacture, and methods of treating emissions in an exhaust stream.

BACKGROUND

Diesel engine exhaust is a heterogeneous mixture that contains particulate emissions such as soot and gaseous emissions such as carbon monoxide, unburned or partially burned hydrocarbons, and nitrogen oxides (collectively referred to as NO_x). Catalyst compositions, often disposed on one or more monolithic substrates, are placed in engine exhaust systems to convert certain or all of these exhaust components to innocuous compounds.

Ammonia selective catalytic reduction (SCR) is a NO_x abatement technology that will be used to meet strict NO_x emission targets in diesel and lean-burn engines. In the ammonia SCR process, NO_x (normally consisting of $NO+NO_2$) is reacted with ammonia (or an ammonia precursor such as urea) to form dinitrogen (N_2) over a catalyst typically composed of base metals. This technology is capable of NO_x conversions greater than 90% over a typical diesel driving cycle, and thus it represents one of the best approaches for achieving aggressive NO_x abatement goals.

A characteristic feature of some ammonia SCR catalyst materials is a propensity to retain considerable amounts of ammonia on Lewis and Brønsted acidic sites on the catalyst surface during low temperature portions of a typical driving cycle. A subsequent increase in exhaust temperature can cause ammonia to desorb from the ammonia SCR catalyst surface and exit the exhaust pipe of the vehicle. Overdosing ammonia in order to increase NO_x conversion rate is another potential scenario where ammonia may exit from the ammonia SCR catalyst.

Ammonia slip from the ammonia SCR catalyst presents a number of problems. The odor threshold for NH_3 is 20 ppm in air. Eye and throat irritation are noticeable above 100 ppm, skin irritation occurs above 400 ppm, and the IDLH is 500 ppm in air. NH_3 is caustic, especially in its aqueous form. Condensation of NH_3 and water in cooler regions of the exhaust line downstream of the exhaust catalysts will give a corrosive mixture.

Therefore, it is desirable to eliminate the ammonia before it can pass into the tailpipe. A selective ammonia oxidation (AMOx) catalyst is employed for this purpose, with the objective to convert the excess ammonia to N_2. It would be desirable to provide a catalyst for selective ammonia oxidation that is able to convert ammonia at a wide range of temperatures where ammonia slip occurs in the vehicles driving cycle, and can produce minimal nitrogen oxide byproducts. The AMOx catalyst should also produce minimal N_2O, which is a potent greenhouse gas.

SUMMARY

Aspects of the invention include catalyst systems for treating an exhaust gas stream, and methods of preparing catalysts for the treatment of such gas. As used herein, the term "catalyst system" shall include two or more chemical catalytic functions on one substrate or on more than one separate substrate.

According to one aspect of the invention, a catalyst system for treating an exhaust gas stream containing NO_x comprises at least one monolithic catalyst substrate; an undercoat washcoat layer coated on one end of the monolithic substrate, and containing a material composition A effective for catalyzing NH_3 oxidation; and an overcoat washcoat layer coated over a length of the monolithic substrate sufficient to overlay at least a portion of the undercoat washcoat layer, and containing a material composition B effective to catalyze selective catalytic reduction (SCR) of NO_x.

In one embodiment, the substrate is a single monolithic substrate. The monolithic substrate can be a flow-through honeycomb substrate comprising a plurality of fine, substantially parallel gas flow passages extending along the longitudinal axis of the substrate.

In an embodiment, the undercoat washcoat layer covers in the range of about 5% and 100% of the total substrate length, and the overcoat washcoat layer covers in the range of about 5% and 100% of the total substrate length. In one or more embodiments, the undercoat washcoat layer also contains a material composition further effective to catalyze SCR of NO_x.

In one embodiment, the material composition A is effective to remove ammonia with NH_3 conversion greater than about 10% at a temperature greater than about 225° C. and gas hourly space velocity below about 300,000/hr across the monolithic substrate.

In one embodiment, the material composition A comprises a precious metal component dispersed on support particles. The support particles may comprise a refractory metal oxide containing alumina, silica, zirconia, titania, ceria, and physical mixtures or chemical combinations thereof, including atomically doped combinations. In one or more embodiments, the precious metal component contains ruthenium, rhodium, iridium, palladium, platinum, silver, or gold and physical mixtures or chemical combinations thereof, including atomically doped combinations.

In one embodiment, composition B is effective to simultaneously remove NO and NH_3, with NO conversion greater than about 50% and N_2 selectivity greater than about 50% at a temperature greater than about 300° C. and gas hourly space velocity below about 300,000/hr across the monolithic substrate.

In one or more embodiments, the material composition B is effective to remove ammonia with NH_3 conversion of at least 10% and N_2 selectivity of at least 50% at a temperature greater than about 350° C. and gas hourly space velocity below about 300,000/hr across the monolithic substrate and a NO/NH_3 molar ratio less than about 0.10.

In one or more embodiments, the material composition B contains a zeolitic or non-zeolitic molecular sieve. The molecular sieve can be an aluminosilicate molecular sieve having the one of the crystal framework types FAU, MFI, MOR, BEA, as per the designations in the Database of Zeolite Structures published by the International Zeolite Association (IZA).

In a specific embodiment, the material composition B contains an aluminosilicate molecular sieve having a CHA crystal framework type. In a more specific embodiment, the material composition B contains a silicoaluminophosphate molecular sieve having a CHA crystal framework type.

The molecular sieve according to an embodiment of the invention contains a metal from one of the groups VB, VIB, VIIB, VIIIB, IB, or IIB of the periodic table distributed on or within the molecular sieve, the metal being present in an

amount between 0.1% and 10% by wt. of the molecular sieve. The metal may be selected from Cu, Fe, and mixtures or combinations thereof.

Another aspect of the invention pertains to a method of preparing a catalyst system for the treatment of an exhaust stream containing NO_x, the method comprising: coating one end of a monolithic substrate along at least about 5% of the substrate length with an undercoat washcoat layer containing a material composition effective to catalyze oxidation of NH_3; drying and calcining the coated substrate to fix the undercoat washcoat layer onto the substrate; recoating the substrate along at least about 50% of the substrate length with an overcoat washcoat layer containing a material composition effective to catalyze selective catalytic reduction of NO_x, to form one longitudinal zone comprising an SCR composition and a second longitudinal zone comprising an SCR composition overlaying at least part of the undercoat washcoat layer, the SCR composition being compositionally different from the undercoat layer; and drying and calcining the coated substrate to fix the SCR composition onto the substrate in the upstream zone and onto the undercoat washcoat layer in the downstream zone. In one embodiment, the method comprises coating the entire length of the substrate with multiple layers of an SCR composition.

Another aspect of the invention pertains to a method for treating emissions produced in a exhaust gas stream of a lean-burn engine, the method comprising: injecting ammonia or an ammonia precursor into an exhaust gas stream containing one or more of NO_x, CO, or hydrocarbons; passing the exhaust gas stream through an upstream zone of a catalyst system, the upstream zone containing a material composition effective to catalyze selective catalytic reduction of NO_x in a washcoat layer coated on a monolithic substrate, and passing the exhaust gas stream through a downstream zone of a catalyst system, the downstream zone comprising; an undercoat washcoat layer containing a material composition effective to catalyze oxidation of NH_3.

In one embodiment of the methods for treating emissions, the ammonia or ammonia precursor that is unreacted in the upstream zone is selectively oxidized to N_2 in the downstream zone of the catalyst system. In one embodiment, the downstream zone covers in the range of about 5% and 100% of the total substrate length. In one or more embodiments, the monolithic substrate is a flow-through honeycomb substrate comprising plurality of fine, substantially parallel gas flow passages extending along the longitudinal axis of the substrate.

In one or more embodiments, the downstream zone of the catalyst system is effective to remove ammonia with NH_3 conversions of at least 10% and N_2 selectivities of at least 50% at temperatures greater than about 225° C. In an embodiment, the SCR composition in the upstream zone is effective to remove ammonia with NH_3 conversion of at least 10% and N_2 selectivity of at least 50% at a temperature greater than about 350° C. and gas hourly space velocity below about 300,000/hr across the monolithic substrate and a NO/NH_3 molar ratio less than about 0.10. The specific catalyst compositions for the catalysts used in the method aspect may include the catalysts described above with respect to the system.

BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings illustrate embodiments of the invention. It is to be understood that the Figures are not intended to be to scale and that certain features such as monolith channels may be increased in size to show features according to embodiments of the invention.

FIG. **1**A shows a schematic of a catalyst monolith and the washcoat geometry in an individual monolith channel after coating with an undercoat;

FIG. **1**B shows a schematic of a catalyst monolith and the washcoat geometry in an individual monolith channel after coating the entire substrate from FIG. **1**A with an overcoat;

FIG. **2** is a schematic view illustrating the conversion of NH_3 to N_2 in a catalyst system according to one or more embodiments;

FIG. **3** is a schematic of an engine emission treatment system, in accordance with one embodiment of the present invention;

FIG. **4**A shows an SEM image of the uniform catalyst H, consisting of a physical mixture of 0.58 wt % Pt supported on γ-alumina, and copper(II)-exchanged chabazite zeolite;

FIG. **4**B shows an SEM image of the layered catalyst B, consisting of a bottom washcoat layer having 0.58 wt % Pt supported on γ-alumina, and a top washcoat layer having copper(II)-exchanged chabazite zeolite;

FIG. **5**A shows the N_2 selectivity for ammonia oxidation for catalysts B-F as a function of the top washcoat loading;

FIG. **5**B shows the NH_3 lightoff temperature T_{50} for ammonia oxidation for catalysts B-F as a function of the top washcoat loading;

FIG. **6**A shows the N_2 selectivity for ammonia oxidation for catalysts J-M as a function of the top washcoat loading;

FIG. **6**B shows the NH_3 lightoff temperature T_{50} for ammonia oxidation for catalysts J-M as a function of the top washcoat loading;

FIG. **7** shows N_2 selectivity for ammonia oxidation for layered catalysts C and L, and for uniform catalysts H and N;

FIG. **8** shows percent conversion of NO_x and NH_3 for the SCR reaction as a function of temperature for comparative catalysts Y and Z;

FIG. **9** shows the ammonia percent conversion for ammonia oxidation as a function of temperature for catalysts layered catalysts F-I;

FIG. **10** shows NH_3 conversion (solid lines) and N_2 selectivity (dashed lines) for ammonia oxidation catalyzed by the integrated SCR+AMOx catalyst P (open symbols) and a comparative SCR-only catalyst Q (closed symbols);

FIG. **11** shows NO_x conversion (solid lines) and NH_3 conversion (dashed lines) for the SCR reaction catalyzed by the integrated SCR+AMOx catalyst P (open symbols) and a comparative SCR-only catalyst Q (closed symbols) under conditions where inlet $NH_3/NO=1$; and

FIG. **12** shows NO_x conversion (solid lines) and NH_3 conversion (dashed lines) for the SCR reaction catalyzed by the integrated SCR+AMOx catalyst P (open symbols) and a comparative SCR-only catalyst Q (closed symbols) under conditions where inlet $NH_3/NO>1$.

DETAILED DESCRIPTION

Before describing several exemplary embodiments of the invention, it is to be understood that the invention is not limited to the details of construction or process steps set forth in the following description. The invention is capable of other embodiments and of being practiced or being carried out in various ways.

As used in this specification and the appended claims, the singular forms "a", "an" and "the" include plural referents unless the context clearly indicates otherwise. Thus, for example, reference to "a catalyst" includes a mixture of two or more catalysts, and the like. As used herein, the term

"abate" means to decrease in amount and "abatement" means a decrease in the amount, caused by any means. Where they appear herein, the terms "exhaust stream" and "engine exhaust stream" refer to the engine out effluent as well as to the effluent downstream of one or more other catalyst system components including but not limited to a diesel oxidation catalyst and/or soot filter.

An aspect of the invention pertains to a catalyst. According to one or more embodiments, the catalyst may be disposed on a monolithic substrate as a washcoat layer. As used herein and as described in Heck, Ronald and Robert Farrauto, *Catalytic Air Pollution Control*, New York: Wiley-Interscience, 2002, pp. 18-19, a washcoat layer consists of a compositionally distinct layer of material disposed on the surface of the monolithic substrate or an underlying washcoat layer. A catalyst can contain one or more washcoat layers, and each washcoat layer can have unique chemical catalytic functions.

In one or more embodiments, bifunctional catalysts are provided. According to one aspect of the invention, a bifunctional catalyst is provided that comprises a modular catalyst system with physically separate compositions for the SCR function and the NH_3 oxidation function. According to one or more embodiments, such modular catalyst systems permit greater flexibility to independently tune the kinetics of the two functions. By doing this, catalyst physical structure can be used to control the sequence of chemical catalytic events, to increase conversion of NO_x and NH_3, and to increase selectivity to N_2. The catalyst compositions for the SCR function and NH_3 oxidation function can reside in discrete washcoat layers on the substrate or, alternatively, the compositions for the SCR and NH_3 oxidation functions can reside in discrete longitudinal zones on the substrate.

The term "SCR function" will be used herein to refer to a chemical process described by the stoichiometric Eq 1.

$$4NO_x+4NH_3+(3-2x)O_2 \rightarrow 4N_2+6H_2O \quad \text{Eq 1}$$

More generally it will refer to any chemical process in which NO_x and NH_3 are combined to produce preferably N_2. The term "SCR composition" refers to a material composition effective to catalyze the SCR function. The term "NH_3 oxidation function" will be used herein to refer to a chemical process described by Eq 2.

$$4NH_3+5O_2 \rightarrow 4NO+6H_2O \quad \text{Eq 2}$$

More generally, it will a refer to a process in which NH_3 is reacted with oxygen to produce NO, NO_2, N_2O, or preferably N_2. The term "NH_3 oxidation composition" refers to a material composition effective to catalyze the NH_3 oxidation function.

As described otherwise herein, one or more embodiments of the present invention provide for a catalyst having an upstream zone that includes a overcoat washcoat layer containing a composition effective for the selective catalytic reduction of NO_x; and a downstream zone that includes an undercoat washcoat layer containing a composition effective for the oxidation of ammonia, and a separate overcoat washcoat layer, effective for the selective catalytic reduction of NO_x, covering at least a portion of the undercoat layer.

The Substrate

According to one or more embodiments, the substrate for the catalyst may be any of those materials typically used for preparing automotive catalysts and will typically comprise a metal or ceramic honeycomb structure. Any suitable substrate may be employed, such as a monolithic flow-through substrate and having a plurality of fine, parallel gas flow passages extending from an inlet to an outlet face of the substrate, such that passages are open to fluid flow. The passages, which are essentially straight paths from their fluid inlet to their fluid outlet, are defined by walls on which the catalytic material is coated as a "washcoat" so that the gases flowing through the passages contact the catalytic material. The flow passages of the monolithic substrate are thin-walled channels which can be of any suitable cross-sectional shape such as trapezoidal, rectangular, square, sinusoidal, hexagonal, oval, circular, etc. Such structures may contain from about 60 to about 1200 or more gas inlet openings (i.e., "cells") per square inch of cross section (cpsi). A representative commercially-available flow-through substrate is the Corning 400/6 cordierite material, which is constructed from cordierite and has 400 cpsi and wall thickness of 6 mil. However, it will be understood that the invention is not limited to a particular substrate type, material, or geometry.

Ceramic substrates may be made of any suitable refractory material, e.g., cordierite, cordierite-α alumina, silicon nitride, zircon mullite, spodumene, alumina-silica magnesia, zircon silicate, sillimanite, magnesium silicates, zircon, petalite, α alumina, aluminosilicates and the like.

The substrates useful for the catalysts according to one or more embodiments of the present invention may also be metallic in nature and be composed of one or more metals or metal alloys. Exemplary metallic supports include the heat resistant metals and metal alloys such as titanium and stainless steel as well as other alloys in which iron is a substantial or major component. Such alloys may contain one or more of nickel, chromium and/or aluminum, and the total amount of these metals may comprise at least 15 wt. % of the alloy, e.g., 10-25 wt. % of chromium, 3-8 wt. % of aluminum and up to 20 wt. % of nickel. The alloys may also contain small or trace amounts of one or more other metals such as manganese, copper, vanadium, titanium and the like. The metallic substrates may be employed in various shapes such as corrugated sheet or monolithic form. A representative commercially-available metal substrate is manufactured by Emitec. However, it will be understood that the invention is not limited to a particular substrate type, material, or geometry. The surface of the metal substrates may be oxidized at high temperatures, e.g., 1000° and higher, to form an oxide layer on the surface of the substrate, improving the corrosion resistance of the alloy. Such high temperature-induced oxidation may also enhance the adherence of the refractory metal oxide support and catalytically-promoting metal components to the substrate.

SCR Composition

In accordance with one or more embodiments of the invention, a component effective to catalyze the SCR function (herein referred to as an "SCR component") is utilized in a washcoat as part of a NO_x abatement catalyst composition. Typically, the SCR component is part of a composition that includes other components in a washcoat. However, in one or more embodiments the NO_x abatement catalyst composition may include only the SCR component.

In some embodiments, the invention utilizes an SCR component which consists of a microporous inorganic framework or molecular sieve onto which a metal from one of the groups VB, VIB, VIIB, VIIIB, IB, or IIB of the periodic table has been deposited onto extra-framework sites on the external surface or within the channels, cavities, or cages of the molecular sieves. Metals may be in one of several forms, including, but not limited to, zerovalent metal atoms or clusters, isolated cations, mononuclear or polynuclear oxycations, or as extended metal oxides. In specific embodiments, the metals include iron, copper, and mixtures or combinations thereof.

In certain embodiments, the SCR component contains in the range of about 0.10% and about 10% by weight of a group VB, VIB, VIIB, VIIIB, IB, or IIB metal located on extraframework sites on the external surface or within the channels, cavities, or cages of the molecular sieve. In preferred embodiments, the extraframework metal is present in an amount of in the range of about 0.2% and about 5% by weight.

The microporous inorganic framework may consist of a microporous aluminosilicate or zeolite having any one of the framework structures listed in the *Database of Zeolite Structures* published by the International Zeolite Association (IZA). The framework structures include, but are not limited to those of the CHA, FAU, BEA, MFI, MOR types. Non-limiting examples of zeolites having these structures include chabazite, faujasite, zeolite Y, ultrastable zeolite Y, beta zeolite, mordenite, silicalite, zeolite X, and ZSM-5. Some embodiments utilize aluminosilicate zeolites that have a silica/alumina molar ratio (defined as SiO_2/Al_2O_3 and abbreviated as SAR) from at least about 5, preferably at least about 20, with useful ranges of from about 10 to 200.

In a specific embodiment, the SCR component includes an aluminosilicate molecular sieve having a CHA crystal framework type, an SAR greater than about 15, and copper content exceeding about 0.2 wt %. In a more specific embodiment, the SAR is at least about 10, and copper content from about 0.2 wt % to about 5 wt %. Zeolites having the CHA structure, include, but are not limited to natural chabazite, SSZ-13, LZ-218, Linde D, Linde R, Phi, ZK-14, and ZYT-6. Other suitable zeolites are also described in U.S. patent application Ser. No. 12/038,423, entitled "Copper CHA Zeolite Catalysts," the entire content of which is incorporated herein by reference, published as PCT International Publication No. WO 2008/106519.

According to one or more embodiments of the invention, SCR compositions which include non-zeolitic molecular sieves are provided. As used herein, the terminology "non zeolitic molecular sieve" refers to corner sharing tetrahedral frameworks where at least a portion of the tetrahedral sites are occupied by an element other than silicon or aluminum. Non-limiting examples of such molecular sieves include aluminophosphates and metal-aluminophosphates, wherein metal could include silicon, copper, zinc or other suitable metals. Such embodiments may include a non-zeolitic molecular sieve having a crystal framework type selected from CHA, FAU, MFI, MOR, and BEA.

Non-zeolitic compositions can be utilized in the SCR component according to embodiments of the present invention. Specific non-limiting examples include sillicoaluminophosphates SAPO-34, SAPO-37, SAPO-44. Synthesis of synthetic form of SAPO-34 is described in U.S. Pat. No. 7,264,789, which is hereby incorporated by reference. A method of making yet another synthetic non-zeolitic molecular sieve having chabazite structure, SAPO-44, is described in U.S. Pat. No. 6,162,415, which is hereby incorporated by reference.

SCR compositions consisting of vanadium supported on a refractory metal oxide such as alumina, silica, zirconia, titania, ceria and combinations thereof are also well known and widely used commercially in mobile applications. Typical compositions are described in U.S. Pat. Nos. 4,010,238 and 4,085,193, of which the entire contents are incorporated herein by reference. Compositions used commercially, especially in mobile applications, comprise TiO_2 on to which WO_3 and V_2O_5 have been dispersed at concentrations ranging from 5 to 20 wt. % and 0.5 to 6 wt. %, respectively. These catalysts may contain other inorganic materials such as SiO_2 and ZrO_2 acting as binders and promoters.

NH_3 Oxidation Composition

In accordance with one or more embodiments of the invention, a composition effective to catalyze the NH_3 oxidation function (herein referred to as an "NH_3 oxidation component") is utilized in a NO_x abatement catalyst. The ammonia contained in an exhaust gas stream is reacted with oxygen over the NH_3 oxidation component to form N_2 over a catalyst according to Eq 1.

According to one or more embodiments, the NH_3 oxidation component may be a supported precious metal component which is effective to remove ammonia from the exhaust gas stream. In one or more embodiments, the precious metal component includes ruthenium, rhodium, iridium, palladium, platinum, silver or gold. In specific embodiments, the precious metal component includes physical mixtures and chemical and atomically-doped combinations of ruthenium, rhodium, iridium, palladium, platinum, silver and gold. In a more specific embodiment, the precious metal component includes platinum. In an even more specific embodiment, the platinum is present in an amount in the range of about 0.008% to about 2% by wt (metal), based on Pt support loading.

According to one or more embodiments, the precious metal component is deposited on a high surface area refractory metal oxide support. Examples of suitable high surface area refractory metal oxides include, but are not limited to, alumina, silica, titania, ceria, and zirconia, as well as physical mixtures, chemical combinations and/or atomically-doped combinations thereof. In specific embodiments, the refractory metal oxide may contain a mixed oxide such as silica-alumina, amorphous or crystalline aluminosilicates, alumina-zirconia, alumina-lanthana, alumina-chromia, alumina-baria, alumina-ceria, and the like. An exemplary refractory metal oxide comprises high surface area γ-alumina having a specific surface area of about 50 to about 300 m^2/g.

As otherwise mentioned herein, the NH_3 oxidation component may include a zeolitic or non-zeolitic molecular sieve, which may have any one of the framework structures listed in the *Database of Zeolite Structures* published by the International Zeolite Association (IZA). The framework structures include, but are not limited to those of the CHA, FAU, BEA, MFI, and MOR types. In one embodiment, a molecular sieve component may be physically mixed with an oxide-supported platinum component. In an alternative embodiment, platinum may be distributed on the external surface or in the channels, cavities, or cages of the molecular sieve.

The NH_3 oxidation composition may contain a component active for the ammonia SCR function. The SCR component may consist of any one of the SCR components described in the preceding section. In on embodiment, the NH_3 oxidation component consists of a physical mixture of an oxide-supported platinum component and an SCR component. In an alternative embodiment, platinum may be distributed on the external surface or in the channels, cavities, or cages of the SCR component.

Washcoat Layers

According to one or more embodiments, the SCR component and the NH_3 oxidation component can be applied in washcoat layers, which are coated upon and adhered to the substrate.

For example, a washcoat layer of a composition containing an NH_3 oxidation component may be formed by preparing a mixture or a solution of a platinum precursor in a suitable solvent, e.g. water. Generally, from the point of view of economics and environmental aspects, aqueous solutions of soluble compounds or complexes of the platinum are pre-

ferred. Typically, the platinum precursor is utilized in the form of a compound or complex to achieve dispersion of the platinum precursor on the support. For purposes of the present invention, the term "platinum precursor" means any compound, complex, or the like which, upon calcination or initial phase of use thereof, decomposes or otherwise converts to a catalytically active form. Suitable platinum complexes or compounds include, but are not limited to platinum chlorides (e.g. salts of $[PtCl_4]^{2-}$, $[PtCl_6]^{2-}$), platinum hydroxides (e.g. salts of $[Pt(OH)_6]^{2-}$), platinum ammines (e.g. salts of $[Pt(NH_3)_4]^{2+}$, $[Pt(NH_3)_4]^{4+}$), platinum hydrates (e.g. salts of $[Pt(OH_2)_4]^{2+}$), platinum bis(acetylacetonates), and mixed compounds or complexes (e.g. $[Pt(NH_3)_2(Cl)_2]$). A representative commercially-available platinum source is 99% ammonium hexachloroplatinate from Strem Chemicals, Inc., which may contain traces of other precious metals. However, it will be understood that this invention is not restricted to platinum precursors of a particular type, composition, or purity. A mixture or solution of the platinum precursor is added to the support by one of several chemical means. These include impregnation of a solution of the platinum precursor onto the support, which may be followed by a fixation step incorporating acidic component (e.g. acetic acid) or a basic component (e.g. ammonium hydroxide). This wet solid can be chemically reduced or calcined or be used as is. Alternatively, the support may be suspended in a suitable vehicle (e.g. water) and reacted with the platinum precursor in solution. This latter method is more typical when the support is a zeolite, and it is desired to fix the platinum precursor to ion-exchange sites in the zeolite framework. Additional processing steps may include fixation by an acidic component (e.g. acetic acid) or a basic component (e.g. ammonium hydroxide), chemical reduction, or calcination.

In one or more embodiments utilizing washcoat layers of an SCR composition, the layer can contain a zeolitic or non-zeolitic molecular sieve on which has been distributed a metal from one of the groups VB, VIB, VIIB, VIIIB, IB, or IIB of the periodic table. An exemplary metal of this series is copper. Exemplary molecular sieves, include, but are not limited to zeolites having one of the following crystal structures CHA, BEA, FAU, MOR, and MFI. A suitable method for distributing the metal on the zeolite is to first prepare a mixture or a solution of the metal precursor in a suitable solvent, e.g. water. Generally, from the point of view of economics and environmental aspects, aqueous solutions of soluble compounds or complexes of the metal are preferred. For purposes of the present invention, the term "metal precursor" means any compound, complex, or the like which, can be dispersed on the zeolite support to give a catalytically-active metal component. For the exemplary Group IB metal copper, suitable complexes or compounds include, but are not limited to anhydrous and hydrated copper sulfate, copper nitrate, copper acetate, copper acetylacetonate, copper oxide, copper hydroxide, and salts of copper ammines (e.g. $[Cu(NH_3)_4]^{2+}$). A representative commercially-available copper source is 97% copper acetate from Strem Chemicals, Inc., which may contain traces of other metals, particularly iron and nickel. However, it will be understood that this invention is not restricted to metal precursors of a particular type, composition, or purity. The molecular sieve can be added to the solution of the metal component to form a suspension. This suspension can be allowed to react so that the copper component is distributed on the zeolite. This may result in copper being distributed in the pore channels as well as on the outer surface of the molecular sieve. Copper may be distributed as copper (II) ions, copper (I) ions, or as copper oxide. After the copper is distributed on the molecular sieve, the solids can be separated from the liquid phase of the suspension, washed, and dried. The resulting copper-containing molecular sieve may also be calcined to fix the copper.

To apply a washcoat layer according to one or more embodiments of the invention, finely divided particles of a catalyst, consisting of the SCR component, the NH_3 oxidation component, or a mixture thereof, are suspended in an appropriate vehicle, e.g., water, to form a slurry. Other promoters and/or stabilizers and/or surfactants may be added to the slurry as mixtures or solutions in water or a water-miscible vehicle. In one or more embodiments, the slurry is comminuted to result in substantially all of the solids having particle sizes of less than about 10 microns, i.e., in the range of about 0.1-8 microns, in an average diameter. The comminution may be accomplished in a ball mill, continuous Eiger mill, or other similar equipment. In one or more embodiments, the suspension or slurry has a pH of about 2 to less than about 7. The pH of the slurry may be adjusted if necessary by the addition of an adequate amount of an inorganic or an organic acid to the slurry. The solids content of the slurry may be, e.g., about 20-60 wt. %, and more particularly about 35-45 wt. %. The substrate may then be dipped into the slurry, or the slurry otherwise may be coated on the substrate, such that there will be deposited on the substrate a desired loading of the catalyst layer. Thereafter, the coated substrate is dried at about 100° C. and calcined by heating, e.g., at 300-650° C. for about 1 to about 3 hours. Drying and calcination are typically done in air. The coating, drying, and calcination processes may be repeated if necessary to achieve the final desired gravimetric amount of the catalyst washcoat layer on the support. In some cases, the complete removal of the liquid and other volatile components may not occur until the catalyst is placed into use and subjected to the high temperatures encountered during operation.

After calcining, the catalyst washcoat loading can determined through calculation of the difference in coated and uncoated weights of the substrate. As will be apparent to those of skill in the art, the catalyst loading can be modified by altering the solids content of the coating slurry and slurry viscosity. Alternatively, repeated immersions of the substrate in the coating slurry can be conducted, followed by removal of the excess slurry as described above.

Method of Preparing a Catalyst

As shown in FIG. **1**, a catalyst according to one or more embodiments of the present invention can be prepared in a two-step process. In the first step, shown in FIG. **1**A, a carrier substrate **100**, which, in specific embodiments, contains channels **110** of dimensions in the range of about 100 channels/in^2 and 1000 channels/in^2, is coated with an undercoat washcoat layer **200**, having a composition effective for catalyzing the removal of NH_3. For ease of illustration of the washcoat, only a single channel **110** is shown. The undercoat washcoat layer **200** is applied to one end of the substrate **100**, distributed, dried, and calcined as described in the preceding section. The substrate shown in FIG. **1**A has an upstream or inlet zone **140** and a downstream or outlet zone **130**. In one embodiment, the NH_3 oxidation component in layer **200** is applied in the range of about 5% to about 100% of the substrate length. In a specific embodiment, the NH_3 oxidation component is applied to between 10 and 40% of the substrate length.

In the second step, an SCR composition that contains an SCR component is applied as overcoat washcoat layer **300**, which is shown as an overcoat layer to the entire length of the substrate **100**, as shown in FIG. **1**B. To reach the required loading specified for the SCR component, the second coating step may be repeated to form multiple coatings of the SCR

composition, to collectively form the overcoat layer **300**. The overcoat layer is dried and calcined as described in the preceding section. These two steps yield a catalyst having an upstream or inlet zone **140** (heretofore referred to as the "SCR zone") comprising only the SCR composition. The downstream or outlet zone **130** (heretofore referred to as the "AMOx zone") comprises an undercoat washcoat layer **200** containing the NH_3 oxidation component and an overcoat washcoat layer **300** containing the SCR component. The generation of a two-layer outlet zone that physically separates the NH_3 oxidation component and the SCR component is an important feature affecting the performance of the catalyst, and distinguishes this particular methodology for preparation of an integrated SCR+AMOx catalyst.

In one embodiment, the upstream zone comprises an SCR catalyst washcoat layer disposed on the carrier and the downstream zone comprises an undercoat layer containing an NH_3 oxidation component disposed on the carrier and an SCR catalyst washcoat layer disposed on at least a portion of the undercoat layer. According to a specific embodiment, the ratio of the front zone length to the total substrate length is at least about 0.4. In a more specific embodiment the ratio of the front zone length to the total substrate length is in the range of about 0.5 and about 0.9. In an even more specific embodiment, the ratio of the front zone length to the total substrate length is in the range of about 0.6 and about 0.8.

After the overcoat washcoat layer is applied, the finished catalyst is placed in the exhaust system, taking care that the orientation is such that the SCR zone is disposed in the upstream position **140** of the catalyst. In alternative embodiments, additional layers may be applied to the overcoat layer.

In an alternative embodiment, the NH_3 oxidation component is applied as an undercoat layer over the entire length of the substrate in the first step. In the second step, the SCR component is applied as an overcoat layer over the entire length of the substrate. This yields a catalyst in which the AMOx zone **200** covers the entire length of the substrate. This catalyst is heretofore referred to as a "standalone AMOx."

Method for Treating Emissions

Another aspect of the present invention includes a method of treating emissions produced in the exhaust gas stream of an engine. The exhaust gas stream can include one or more of NO_x, CO, hydrocarbons, and ammonia. In one or more embodiments, the method includes injecting ammonia or an ammonia precursor into an exhaust gas stream and then passing the exhaust gas stream first through an upstream SCR zone described herein to remove NO_x by the SCR function. In such embodiments, the exhaust gas stream is then passed through a downstream AMOx zone to remove ammonia by the NH_3 oxidation function. The downstream catalyst zone may also serve to oxidize one or more of CO, hydrocarbons, in addition to ammonia.

In one embodiment, the upstream SCR zone and the downstream AMOx zone are disposed on a single catalyst substrate. The SCR zone comprised in the range of about 50% to about 90% of the substrate length, and consists of only the SCR component. The AMOx zone comprises in the range of about 5% to about 50% of the substrate length, and consists of an undercoat layer containing the NH_3 oxidation component and an overcoat layer containing the SCR component.

In an alternative embodiment of the method, the upstream SCR zone is disposed on one carrier substrate, and the downstream AMOx zone is disposed on a separate carrier substrate. In this embodiment, the AMOx zone is prepared as a standalone AMOx as described above. The volume of the downstream standalone AMOx catalyst is in the range of about 10% to about 100% of the volume of the upstream SCR catalyst, and consists of an undercoat layer containing the NH_3 oxidation component and an overcoat layer containing the SCR component.

In both embodiments above, the AMOx zone consists of two compositionally and functionally distinct layers. The undercoat layer consists of a supported precious metal component and functions to oxidize ammonia according to Eq 2. The overcoat layer is free of precious metal, and consists of a catalyst composition effective for the conversion of NO_x and ammonia to dinitrogen. FIG. **2** illustrates how these two layers function together to increase the N_2 selectivity for NH_3 oxidation in the AMOx catalyst. Ammonia molecules that are desorbed from an SCR catalyst under conditions where it cannot be quickly consumed by a molecule of NO_x (e.g., under a thermal desorption event) move down the channel **110** while colliding with the washcoat layer **300** in the upstream zone **140**, comprising an SCR catalyst. The molecule can diffuse into and out of the washcoat layer **300**, but it is not otherwise converted by the catalyst until it enters the downstream zone **130** and contacts the undercoat layer **200**, which contains a composition that includes an NH_3 oxidation component. In the undercoat layer **200**, the ammonia is initially converted to NO, which subsequently may diffuse to the overcoat layer **300**. In the overcoat layer containing an SCR catalyst composition, the NO may react with NH_3 to form N_2, thereby increasing the net selectivity to N_2.

Placing the supported precious metal in the bottom washcoat layer underneath the SCR component in the overcoat layer restricts NO to be generated only in the undercoat layer. This has the effect of increasing the average residence lifetime of NO within the catalyst washcoat layers. As the residence time of the NO is increased, NO has a higher probability to collide with a molecule of ammonia in the SCR washcoat layer and to produce N_2, which is ultimately released from the catalyst.

In use, the upstream SCR zone **140** of the catalyst is primarily responsible for removing NO_x emissions from the exhaust by ammonia selective catalytic reduction reaction. The downstream AMOx zone is primarily responsible for the ammonia oxidation function. As discussed otherwise herein, the downstream zone **130**, having an overlayer of the SCR composition will have SCR activity and can further function in NO_x abatement. In this manner, the AMOx zone can contribute to net NO_x removal. In addition, at elevated temperatures, some SCR compositions, particularly copper-based SCR catalysts, can also have appreciable ammonia oxidation activity even in the absence of a precious metal component. Furthermore, copper-based SCR catalyst compositions can convert NH_3 to N_2 with high selectivity at temperatures above 350° C. In one or more embodiments, the SCR zone can thereby contribute to abatement of excess ammonia.

Another aspect of the present invention is directed to an emission treatment system comprising one or more additional components for the treatment of diesel exhaust gas emissions. Diesel engine exhaust is a heterogeneous mixture which contains not only gaseous emissions such as carbon monoxide, unburned hydrocarbons and NO_x, but also condensed phase materials (liquids and solids) which constitute the particulates or particulate matter. Often, catalyst compositions and substrates on which the compositions are disposed are provided in diesel engine exhaust systems to convert certain or all of these exhaust components to innocuous components. For example, diesel exhaust systems can contain one or more of a diesel oxidation catalyst and a soot filter, in addition to a catalyst for the reduction of NO_x. Embodiments of the present invention can be incorporated into diesel exhaust gas treat-

ment systems known in the art. One such system is disclosed in U.S. Pat. No. 7,229,597, which is incorporated herein by reference in its entirety.

An example of an emission treatment system may be more readily appreciated by reference to FIG. **3**, which depicts a schematic representation of an emission treatment system **400**, in accordance with this embodiment of the present invention. An exhaust gas stream containing gaseous pollutants (e.g., unburned hydrocarbons, carbon monoxide and NO_x) and particulate matter is conveyed via line **510** from an engine **500** to a diesel oxidation catalyst (DOC) **600**. In the DOC, unburned gaseous and non-volatile hydrocarbons and carbon monoxide are largely combusted to form carbon dioxide and water. In addition, a proportion of the NO of the NO_x component may be oxidized to NO_2 in the DOC. The exhaust stream is next conveyed via line **610** to a catalyzed soot filter (CSF) **700**, which traps particulate matter present within the exhaust gas stream. The CSF is optionally catalyzed for passive regeneration. After removal of particulate matter, via CSF **700**, the exhaust gas stream is conveyed via line **710** to a downstream catalyst **800**, according to the embodiments described herein, for the treatment and/or conversion of NO_x and ammonia.

TABLE 1

Ammonia oxidation catalysts based on γ-alumina-supported Pt and zeolite-based SCR compositions

	Pt support[a] g/in^3	Pt wt % (metal)	Total Pt g/ft^3	Cocatalyst g/in^3	Cocatalyst composition	NH_3 conv[b] 250° C.	N_2 sel[c] 250° C.	N_2 sel[c] 400° C.
1A	0.55	0.58	5.52	0.00	—	96	58	18
1B	0.51	0.58	5.09	0.00	—	96	53	14
1C	0.47	0.58	4.67	2.03	CuCHA[d]	89	68	96
1D	0.47	0.58	4.67	0.93	CuCHA[d]	91	67	78
1E	0.47	0.58	4.67	1.11	CuCHA[d]	89	72	92
1F	0.47	0.58	4.67	1.82	CuCHA[d]	88	74	95
1G[e]	0.47	0.58	4.67	1.82	CuCHA[d]	84	77	81
1H[f]	0.40	0.58	3.99	2.06	CuCHA[d]	79	82	82
1I[e,f]	0.43	0.58	4.33	2.23	CuCHA[d]	56	92	71
1K	0.51	0.57	5.00	1.61	FeBEA[g]	94	58	74
1L	0.55	0.57	5.43	2.16	FeBEA[g]	94	57	85
1M	0.51	0.57	5.00	2.97	FeBEA[g]	90	59	94
1N[f]	0.48	0.57	4.74	2.40	FeBEA[g]	96	58	69
1Y[h]	—	—	—	2.90	CuCHA[d]	—	—	—
1Z[i]	—	—	—	3.00	FeBEA[g]	—	—	—

[a] γ-Al_2O_3(SBA-150)
[b] percent NH_3 conversion
[c] percent N_2 selectivity
[d] 2.3% Cu by wt (metal) on SSZ-13, SAR = 30
[e] Aged 750° C., 5 hr, 10% H_2O/air
[f] Uniform physical mixture of supported Pt and zeolite loaded as single layer
[g] 1.2% Fe by wt (metal) on beta zeolite, SAR = 30
[h] Aged 655° C., 25 hr, 10% H2O/air
[i] Aged 750° C., 25 hr, 10% H2O/air.

Without intending to limit the invention in any manner, embodiments of the present invention will be more fully described by the following examples.

PREPARATION OF SAMPLES 1A-1I

A series of catalysts 1A-1I was prepared as described in Table 1. All of the catalysts consist of powders disposed on cylindrical 1.0 inch OD×3.0 inch long cordierite honeycomb monoliths with channel dimensions of 400 cpsi and wall thickness of 6 mil. These catalysts were prepared by first immobilizing Pt(IV) onto γ-alumina (SBA-150) by incipient wetness impregnation of $Pt(OH)_6^{2-}$ at pH 9.5, followed by fixation with acetic acid. The resulting yellow solid contained about 0.58 wt % Pt on a volatile-free solids basis. The solid was suspended in deionized water and passed through a continuous mill to reduce the particle size. The monolith substrate was dipped into the resulting slurry, drained, and the excess slurry removed by blowing compressed air through the channels. The monolith sample was dried and calcined at between 450-600° C. Comparative samples 1A and 1B, consisting only of Pt on Al_2O_3 were set aside at this point. The iron or copper-exchanged zeolite was suspended in deionized water and the suspension milled to decrease particle size. Monoliths, to which a supported Pt washcoat had already been applied as described above, were dipped in the resulting slurry, drained, and the excess slurry was removed by compressed air. The monolith samples were dried and calcined at 450° C. to give layered catalysts 1C-1G and 1K-1M. Uniform catalysts 1H, 1I, and 1N were made by combining the Pt on SBA-150 slurries and the appropriate metal-exchanged zeolite slurries in the desired proportion, and dipping fresh monoliths into the combined slurry. The cores were dried and then calcined at 450° C.

PREPARATION OF SAMPLES 1K-1N

A series of catalysts 1K-1N was prepared as described in Table 1. All of the catalysts consist of powders disposed on cylindrical 1.0 inch OD×3.0 inch long cordierite honeycomb monoliths with channel dimensions of 400 cpsi and wall thickness of 6 mil. The Pt on γ-alumina undercoat layer was prepared and applied to 1K-1N in exactly the same manner as described above. The overlayer was applied to 1K-1M as described above for the CuCHA overlayer, except that FeBEA, containing 1.5 wt % Fe on a volatile free solids basis and having SAR=30, was substituted for the CuCHA material. The uniform catalyst 1N was made by combining the Pt on SBA-150 slurry and the FeBEA slurries in the desired

proportion, and dipping fresh monoliths into the combined slurry, followed by drying and calcining at 450° C.

AGING OF SAMPLES 1A-1Z

Prior to analysis or evaluation, all of the catalysts were thermally aged in air at 750° C. for 5 hrs except where otherwise noted in Table 1. Thermal agings of catalysts were done in a box furnace. The aging protocol serves a dual purpose. First, meaningful evaluation results can only be obtained under conditions where the catalyst activity does not change over several evaluation runs. Thermal annealing insures that the catalyst is at a steady-state with respect to thermal changes. Second, catalysts were evaluated under thermal conditions that model a reasonable fraction of vehicle life to insure that the catalyst activity after long-term field usage will be adequate.

EXAMPLE 1

The compositional architecture of the catalysts was visualized using SEM. FIG. **4**A shows a scanning electron micrograph of comparative catalyst 1H, clearly showing grains of γ-alumina uniformly dispersed throughout the washcoat depth. To achieve the desired catalyst loading in the uniform catalyst, the powder slurry was applied in three coating steps, and this is evident in the boundary between the layers. These do not constitute boundaries between different compositions, however, and so catalyst 1H does not fit the present definition of a layered catalyst. FIG. **4**B shows a micrograph of representative catalyst 1C, which has bulk composition and total washcoat loading comparable to 1H. However, in catalyst C the Pt/Al_2O_3 material is localized in a thin layer at the monolith surface, with essentially no γ-alumina in the upper washcoat layer. The SEM images indicate that the desired compositional layering effect can be achieved, where the Pt has been deposited and isolated deep in the catalyst washcoat.

EXAMPLE 2

The catalysts in Table 1 were evaluated for ammonia oxidation activity in a laboratory model gas reactor operated at gas feed conditions as follows: NH_3=500 ppm, O_2=10% (delivered as house air), H_2O=5%, balance=N_2. All evaluations were done at a GHSV=100,000/hr on cores that were 3 in (7.62 cm) in length, giving a linear flow velocity of 2.11 m/sec. For a channel dimension of 1.27 mm and T=300° C., the Reynolds number of 9.1 for the system, so that the reactor operates in a laminar flow regime.

The data in FIG. **5**A show N_2 selectivity for samples 1B-1F, in which the top washcoat composition consists of copper (II) exchanged chabazite zeolite, 2.9% Cu by wt. Selectivity was evaluated at 250° C. (square symbols) and 400° C. (round symbols). The N_2 selectivity is a function of the CuCHA content, especially at 400° C. Catalyst 1C, containing only Pt on Al_2O_3, gave only 15% selectivity, whereas samples having more than 1.4 g/in^3 CuCHA present as an overlayer on top of the Pt/Al_2O_3 layer give greater than 90% selectivity to N_2. At 250° C. the dependence of N_2 selectivity on CuCHA is not as strong, but there is still an increase from 55% to 75% N_2 selectivity as CuCHA is increased fro zero to 1.4 g/in^3. These data show the value of the SCR co-catalyst overlayer in tuning the N_2 selectivity to higher values. Furthermore, the data in FIG. **5**B show that the lightoff temperature T_{50} lies between 220° C. and 235° C. with no obvious trend, indicating no substantial penalty NH_3 activity due to the presence of the topcoat.

EXAMPLE 3

The catalysts 1J-1N in Table 1 were evaluated for NH_3 oxidation in a laboratory model gas reactor as described above. FIG. **6**A shows the N_2 selectivity for catalysts J-M as a function of the top washcoat loading. The N_2 selectivity is a function of the FeBEA content, especially at 400° C., but the trend in selectivity as a function of FeBEA loading is less steep than for the CuCHA-based catalysts. The data shows that it takes a considerably higher loading of the FeBEA cocatalyst to achieve the same N_2 selectivity as with the CuCHA cocatalyst. At 250° C. the N_2 selectivity is essentially invariant as a function of FeBEA loading even up to FeBEA loadings of 3.0 g/in^3. The data in FIG. **6**B shows that the lightoff temperature T_{50} lies between 220° C. and 230° C. for all of the catalysts 1J-1N with no obvious trend, again indicating no substantial penalty NH_3 activity due to the presence of the topcoat.

EXAMPLE 4

FIG. **7** compares the N_2-selectivity of aged AMOx catalysts as a function of the catalyst compositional microstructure and as a function of the co-catalyst. Selectivity was evaluated at 400° C. For layered catalysts 1C and 1L, based on CuCHA and FeBEA respectively, the data show that the layered structure, with the supported Pt component in the undercoat layer, gives higher N_2 selectivity than the compositionally equivalent uniform catalysts 1H and 1N, in which the supported Pt function is physically mixed with the co-catalyst. Thus there is an advantage to the compositionally layered microstructure over the uniform catalysts in terms of N_2 selectivity. FIG. **7** also shows that for either the layered microstructure or the mixed catalyst, the CuCHA co-catalyst gives higher N_2 selectivity than the FeBEA co-catalyst. This is a consequence of the much higher activity of the CuCHA material for the SCR reaction, Eq 1.

This latter fact is supported by the data in FIG. **8**, showing the SCR activity of the comparative catalysts Y (open symbols, 2.6 g/in^3 CuCHA, 2.9 wt % Cu) and Z (closed symbols, 3.0 g/in^3 FeBEA, 1.5 wt % Fe), which have no Pt on alumina undercoats. The SCR evaluation conditions were: NH_3=500 ppm, NO=500 ppm, O_2=10% (delivered as air), H_2O=5%, balance=N_2, GHSV=100,000/hr. Catalysts were aged at 750° C. for 5 hr in 10% H_2O/air. This data shows that NO and NH_3 conversion for a CuCHA-only catalyst under SCR-relevant conditions is considerably higher than for a comparably-loaded FeBEA-only catalyst. This difference relates directly to the higher reaction rate on the CuCHA co-catalyst, which means that the SCR reaction on the CuCHA co-catalyst is kinetically competitive with the ammonia oxidation rate on the supported Pt component. Under such conditions, NO produced by Eq 2 can be rapidly combined with remaining NH_3 to produce N_2, thereby increasing net conversion of NH_3 to N_2.

EXAMPLE 5

Thermal and hydrothermal stability of layered and mixed CuCHA-based AMOx catalysts were probed under NH_3 oxidation conditions, and the data shown in FIG. **9**. Catalysts were thermally aged at 750° C. for 5 hr in air (closed symbols) or 750° C. for 5 hr in 10% H_2O/air (open symbols). The data show that both the layered catalysts 1F and 1G (round symbols) and uniform catalysts H and I (square symbols) have good stability to thermal aging in air at 750° C. for 5 hr, with no loss in activity relative to the freshly prepared catalysts.

After hydrothermal aging in 10% H_2O/air at 750° C. for 5 hr, the data show no loss in activity for the layered catalyst. However, there is a significant loss in activity for the uniform catalyst after hydrothermal aging. These data illustrate the advantage of greater physical separation of the Pt component and the copper-containing component in achieving hydrothermal stability in catalyst mixtures.

PREPARATION OF SAMPLES 1P and 1Q

An integrated SCR+AMOx catalyst 1P was produced based on the scheme illustrated in FIG. **2**. Briefly, a 1.0 inch OD×6.0 inch long honeycomb monolith substrate having 400 cpsi and 6 mil wall thickness was coated with a slurry containing 0.57 wt % Pt supported on SBA-150, in a 1.25 inch long zone on one end, followed by drying and calcination at 450° C. The slurry preparation process was described above. The target washcoat loading in this zone was 0.5 g/in^3, which gives a target Pt loading of 5 g/ft^3 in this zone. The resulting part has a Pt on γ-alumina zone at one end as shown in FIG. **2**A. This same part was then coated from the opposite end with a slurry containing CuCHA, to give a target loading of CuCHA of 2.5 g/in^3 on the entire part, using the slurry preparation and coating process described above. The part was dried and then calcined at 450° C. to affix the CuCHA catalyst to the part. This process gives a part having two zones as shown in FIG. **2***b*: 1) an SCR-only zone 4.75 inches in length that has only CuCHA at 2.5 g/in^3; 2) an AMOx zone 1.25 inches in length that has a 0.5 g/in^3 Pt on SBA-150 as an undercoat layer and 2.5 g/in^3 CuCHA as a top layer. This part functions as a lab-scale model for an SCR+AMOx catalyst generated by an integrated coating process. A comparative catalyst Q was generated by coating a 1.0 inch OD×6.0 inch long honeycomb monolith substrate with 2.5 g/in^3 CuCHA over the entire length of the part, but without having the Pt on γ-alumina undercoat zone. See Table 2 for details of catalyst composition and geometry.

TABLE 2

Integrated SCR + AMOx catalysts

	Zone 1		Zone 2						NH_3 oxidation data	
Catalyst[a]	Zone length In	CuCHA[b] load[c] g/in^3	Zone length in	Pt support[c,d] g/in^3	Pt on support wt % (metal)	Total Pt[c] g/ft^3	CuCHA[b] load[c] g/in^3	NH_3 conv[e] 250° C.	N_2 sel[f] 250° C.	N_2 sel[f] 400° C.
P	4.75	2.32	1.25	0.53	0.58	5.31	2.32	46	96	100
Q	6	2.32	0	—	—	—	—	6.3	99	100

[a]Catalysts in fresh state
[b]2.9% Cu by wt on SSZ-13, SAR = 30
[c]Based on zone length
[d]□-alumina (SBA-150)
[e]percent NH_3 conversion
[f]percent N_2 selectivity

EXAMPLE 6

Catalyst P was evaluated in the fresh state for ammonia oxidation under the following conditions deemed to be relevant for mobile SCR applications: NH_3=200 ppm, O_2=10% (delivered as house air), H_2O=5%, balance=N_2, GHSV=80,000/hr. The space velocity was set using the bulk volume of the entire part. It must be recognized that the AMOx zone on this part is only 20% of the total volume, and so the effective space velocity for the AMOx zone is 400,000/hr. As a result we expect the net conversion of NH_3 to be lower than in testing of the AMOx-only parts above. The part was evaluated with the AMOx zone placed in the downstream (outlet) position. FIG. **10** shows the NH_3 percent conversion and N_2 percent selectivity activity of part P as a function of temperature, and overlays these traces against the comparative part Q. The data show that the SCR-only catalyst Q can oxidize ammonia at high temperatures (T_{50}=330° C.), but that the T_{50} for NH_3 lightoff is moved to approximately 250° C. in the integrated SCR+AMOx catalyst P. In both cases, the NH_3 oxidation yields N_2 almost exclusively, as shown by N_2 selectivities in excess of 90% for all temperatures.

EXAMPLE 7

Catalyst P was evaluated for SCR activity under the following conditions deemed to be relevant in mobile SCR applications: NH_3=200 ppm, NO=200 ppm, O_2=10% (delivered as house air), H_2O=5%, balance=N_2, GHSV=80,000/hr. The data in FIG. **11** show that the SCR-only comparative sample Q and the integrated SCR+AMOx catalyst P give essentially equivalent NO conversion and NH_3 conversion. This data demonstrates that placing the Pt-containing undercoat on the rear 20% portion of an SCR catalyst does not negatively impact the SCR NO_x conversion of the catalyst system.

EXAMPLE 8

The integrated SCR+AMOx catalyst system was finally evaluated under SCR conditions where NH_3 is in excess, in order to evaluate the SCR and AMOx performance simultaneously. The conditions for this evaluation are as follows: NO=200 ppm, O_2=10% (delivered as house air), H_2O=5%, balance=N_2, GHSV=80,000/hr; NH_3=200 ppm (T=200° C.), 226 ppm (250° C.), 257 ppm (350° C.), 828 ppm (450° C.). The NH_3 levels were chosen for each temperature point in order to give 50 ppm NH_3 at the outlet of the control SCR-only catalyst Q. The gas stream was then switched to the integrated SCR+AMOx catalyst P and it was evaluated under the same condition. These data are shown in FIG. **12**. Both P and Q give nearly 100% NO conversion at T≧250° C. Catalyst Q gives slightly higher NO conversion at 200° C. In terms of NH_3 conversion, it is clear that for temperature up to 350° C., the integrated SCR+AMOx catalyst gives higher NH_3 conversion, and hence lower NH_3 slip under the conditions of excess ammonia. Due to the efficient oxidation of ammonia

by the CuCHA catalyst at 450° C., we were unable to obtain a 50 ppm NH_3 slip from the SCR-only comparative catalyst Q at that temperature.

The data in FIGS. **10-12** show that catalyst P achieves three important goals for an integrated SCR+AMOx catalyst: 1) the ammonia oxidizing component oxidizes ammonia in the absence of NO; 2) when placed in the undercoat layer and the rear zone, the ammonia oxidizing component does not negatively impact the SCR NO_x conversion; 3) under relevant SCR conditions with excess NH_3, the integrated SCR+AMOx catalyst can simultaneously remove NO_x and excess ammonia. We also showed that the compositionally layered AMOx zone is more stable to hydrothermal aging than a conventional uniform catalyst architecture based on the same composition.

Reference throughout this specification to "one embodiment," "certain embodiments," "one or more embodiments" or "an embodiment" means that a particular feature, structure, material, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. Thus, the appearances of the phrases such as "in one or more embodiments," "in certain embodiments," "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily referring to the same embodiment of the invention. Furthermore, the particular features, structures, materials, or characteristics may be combined in any suitable manner in one or more embodiments.

Although the invention herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present invention. It will be apparent to those skilled in the art that various modifications and variations can be made to the method and apparatus of the present invention without departing from the spirit and scope of the invention. Thus, it is intended that the present invention include modifications and variations that are within the scope of the appended claims and their equivalents.

What is claimed is:

1. A catalyst system for treating an exhaust gas stream containing NOx, the system comprising:

at least one monolithic catalyst substrate having an inlet end and an outlet end; an undercoat washcoat layer coated on one the outlet end of the monolithic substrate and which covers less than 100% of the total length of the monolithic substrate, and containing a material composition A effective for catalyzing NH3 oxidation;

an overcoat washcoat layer coated over a total length of the monolithic substrate from the inlet end to the outlet end sufficient to overlay the undercoat washcoat layer, and containing a material composition B effective to catalyze selective catalytic reduction (SCR) of NOx; and

wherein material composition A and material composition B are maintained as physically separate catalytic compositions.

2. The catalyst system of claim **1**, wherein the monolithic substrate is a flow-through honeycomb substrate comprising a plurality of fine, substantially parallel gas flow passages extending along the longitudinal axis of the substrate.

3. The catalyst system of claim **2**, wherein the undercoat washcoat layer covers in the range of about 10% and 40% of the total substrate length, and the overcoat washcoat layer covers in the range of about 5% and 100% of the total substrate length.

4. The catalyst system of claim **2**, wherein the substrate is a single monolithic substrate.

5. The catalyst system of claim **2**, wherein the undercoat washcoat layer also contains a material composition further effective to catalyze SCR of NO_x.

6. The catalyst system of claim **2**, wherein the material composition B contains a zeolitic or non-zeolitic molecular sieve.

7. The catalyst system of claim **6**, wherein the material composition B contains an aluminosilicate molecular sieve having the one of the crystal framework types FAU, MFI, MOR, and BEA.

8. The catalyst system of claim **6**, wherein the material composition B contains an aluminosilicate molecular sieve having a CHA crystal framework type.

9. The catalyst system of claim **6**, wherein the material composition B contains a silicoaluminophosphate molecular sieve having the CHA crystal framework type.

10. The catalyst system of claim **6**, wherein the molecular sieve contains a metal from one of the groups VB, VIIB, VIIB, VIIIB, IB, or IIB of the periodic table distributed on or within the molecular sieve, the metal being present in an amount between 0.1% and 10% by wt. of the molecular sieve.

11. The catalyst system of claim **10**, wherein the metal is selected from Cu, Fe, and mixtures or combinations thereof.

12. The catalyst system of claim **10**, wherein the metal is Fe.

13. The catalyst system of claim **10**, wherein the metal is Cu.

14. The catalyst system of claim **2**, wherein the material composition A comprises a precious metal component dispersed on support particles.

15. The catalyst system of claim **14**, wherein the support particles comprise a refractory metal oxide containing alumina, silica, zirconia, titania, ceria, and physical mixtures or chemical combinations thereof, including atomically doped combinations.

16. The catalyst system of claim **14**, wherein the precious metal component comprises ruthenium, rhodium, iridium, palladium, platinum, silver, or gold and physical mixtures or chemical combinations thereof, including atomically doped combinations.

17. A catalyst system for treating an exhaust gas stream containing NO_x, the system comprising:

at least one flow-through honeycomb substrate comprising a plurality of fine, substantially parallel gas flow passages extending along the longitudinal axis of the substrate;

an undercoat washcoat layer coated on the outlet end of the honeycomb substrate, and containing a material composition A comprising a precious metal effective for catalyzing NH_3 oxidation;

an overcoat washcoat layer coated over a total length of the honeycomb substrate from the inlet end to the outlet end of the substrate sufficient to overlay the undercoat washcoat layer, and containing a material composition B free from precious metal effective for catalyzing selective catalytic reduction (SCR) of NO_x;

wherein the undercoat washcoat layer covers in the range of about 10% to about 40% of the total honeycomb substrate length, and wherein material composition A and material composition B are maintained as physically separate catalytic compositions.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO.	: 8,524,185 B2
APPLICATION NO.	: 12/263871
DATED	: September 3, 2013
INVENTOR(S)	: Matthew Tyler Caudle, Martin Dieterle and Scott E. Buzby

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims:

Claim 1, column 19, line 44, "one" should be removed.

Signed and Sealed this
Twenty-ninth Day of July, 2014

Michelle K. Lee

Michelle K. Lee
Deputy Director of the United States Patent and Trademark Office

CERTIFICATE OF SERVICE

I hereby certify that I electronically filed the foregoing with the Clerk of the Court for the United States Court of Appeals for the Federal Circuit by using the appellate CM/ECF system on October 21, 2016.

I certify that all participants in the case are registered CM/ECF users and that service will be accomplished by the appellate CM/ECF system.

Dated: October 21, 2016 /s/ Deanne E. Maynard

CERTIFICATE OF COMPLIANCE WITH RULE 32(a)

This brief complies with the type-volume limitation of Rule 32(a) of the Federal Rules of Appellate Procedure because it contains 12,961 words.

Dated: October 21, 2016 /s/ Deanne E. Maynard

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