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(71) Applicant: **BASF CORPORATION** [US/US]; 100 Park Avenue, Florham Park, New Jersey 07932 (US).

(72) Inventors: **GAO, Xingtao**; 3 Chestnut Ridge Rd, Holmdel, New Jersey 07733 (US). **HARRIS, David Hamilton**; 240 Beechwood Court, Mountainside, New Jersey 07092 (US).

(74) Agent: **LOMPREY, Jeffrey R.** et al.; Foley & Lardner LLP, 3000 K Street N.W., Suite 600, Washington, District of Columbia 20007 (US).

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(54) Title: ATTRITION RESISTANT FLUID CATALYTIC CRACKING ADDITIVES

(57) Abstract: A method for improving attrition resistance in a fluid catalytic cracking (FCC) additive, includes adding a solution of a boron-containing compound to a composition comprising a zeolite and a colloidal oxide binder.

ATTRITION RESISTANT FLUID CATALYTIC CRACKING ADDITIVES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of priority to U.S. Provisional Patent Application No. 62/557,559, filed on September 12, 2017, the disclosure of which is incorporated herein by reference in its entirety.

FIELD

[0002] The present technology is generally related to petroleum refining additives. More specifically, the technology is related to microspherical fluid catalytic cracking (FCC) additives that include a boron-containing compound, and methods of preparing and using such FCC additives.

BACKGROUND

[0003] Catalytic cracking is a petroleum refining process that is applied commercially on a very large scale. Catalytic cracking, and particularly fluid catalytic cracking (FCC), is routinely used to convert heavy hydrocarbon feedstocks to lighter products, such as gasoline and distillate range fractions. In FCC processes, a hydrocarbon feedstock is injected into the riser section of a FCC unit, where the feedstock is cracked into lighter, more valuable products upon contacting hot catalyst circulated to the riser-reactor from a catalyst regenerator.

[0004] Since the 1960s, most commercial fluid catalytic cracking catalysts have contained zeolites as an active component. Such catalysts have taken the form of small particles, called microspheres, containing both an active zeolite component and a non-zeolite component in the form of a high alumina, silica-alumina (aluminosilicate) matrix. The active zeolitic component is incorporated into the microspheres of the catalyst by one of general techniques known in the art, such as those in U.S. Patent No. 4,482,530, or U.S. Pat. No. 4,493,902, each of which is incorporated herein by reference in its entirety. Another technique is *in situ* technique known in the art, such as those in U.S. Patent No. 6,656,347, or U.S. 6,942,784, each of which is incorporated herein by reference in its entirety, microspheres are first formed and then zeolite component is then crystallized in the microspheres themselves to provide microspheres containing both zeolitic and non-zeolitic components.

[0005] Attrition resistant catalysts are necessary for FCC applications as the catalyst is required to circulate from the reactor to the regenerator where coke build up is burnt off. Typically, FCC catalysts are made as spray dried microspheres held together by a binding agent. Such an agent can be silica, alumina, a combination of both, or in the case of *in-situ* catalysts, the zeolite crystals within the microsphere.

[0006] An FCC additive containing kaolin and 10-25% by weight zeolite socony mobil-5 (ZSM-5) has been used to improve gasoline octane and to enhance liquid petroleum gas (LPG) yields. To further increase LPG while minimizing unit activity loss due to dilution, additives with ZSM-5 levels greater than 25% are required. Unfortunately, in microsphere additives that contain higher than 25% ZSM-5 levels, particularly higher than 40% levels, the attrition resistance of the microspheres becomes problematic.

[0007] FCC catalysts are often blends of microspheres containing a catalytically active component (microspheres containing zeolite Y) and additives (microspheres composed of highly calcined kaolin with low surface area, with and without a zeolite, such as ZSM-5). During the process of fluid cracking, the catalyst components attrit forming fines. While formation of fines generally is considered undesirable, formation of particles less than 2.6 microns (microfines) is considered particularly undesirable as these can lead to operational problems in some FCC units while fines less than 2 microns can be important contributors to stack opacity problems.

SUMMARY

[0008] In one aspect, disclosed herein is a method for improving attrition resistance in an FCC additive. The method may include adding a solution of a boron-containing compound to a composition comprising a zeolite and a colloidal oxide binder. In some embodiments, the attrition resistance of the FCC additive is improved by about 10% to about 50% compared to an FCC additive without boron, as measured by Air Jet abrasion. In some embodiments, the FCC additive exhibits an Air Jet attrition rate of about 1%/hr to about 5%/hr. In some embodiments, the FCC additive exhibits an Air Jet attrition rate of about 2%/hr to about 4.5%/hr.

[0009] In a second aspect, disclosed herein is a method of preparing an FCC additive. The method may include dissolving a boron-containing compound in water to prepare an aqueous solution; mixing a zeolite and a colloidal oxide binder to form a slurry; adding the aqueous

solution to the slurry to form a mixture; adding phosphoric acid to the mixture; and spray-drying the mixture to form microspheres of the FCC additive.

[0010] In a third aspect, disclosed herein is an FCC additive prepared by dissolving a boron-containing compound in water to prepare an aqueous solution; mixing a zeolite and a colloidal oxide binder to form a slurry; adding the aqueous solution to the slurry to form a mixture; adding phosphoric acid to the mixture to form an acidified mixture; and spray-drying the acidified mixture to form microspheres of the FCC additive.

[0011] In a fourth aspect, disclosed herein is an FCC additive that may include a boron-containing compound, a zeolite, and a colloidal oxide binder. In some embodiments, the attrition resistance of the FCC additive is improved by about 10% to about 50% compared to an FCC additive without boron, as measured by Air Jet abrasion. In some embodiments, the FCC additive exhibits an Air Jet attrition rate of about 1%/hr to about 5%/hr. In some embodiments, the FCC additive exhibits an Air Jet attrition rate of about 2%/hr to about 4.5%/hr.

[0012] In a fifth aspect, disclosed herein is a method of increasing the yield for light olefins in a fluid catalytic cracking process, the method comprising mixing an FCC catalyst with the FCC additive disclosed herein.

DETAILED DESCRIPTION

[0013] Various embodiments are described hereinafter. It should be noted that the specific embodiments are not intended as an exhaustive description or as a limitation to the broader aspects discussed herein. One aspect described in conjunction with a particular embodiment is not necessarily limited to that embodiment and can be practiced with any other embodiment(s).

[0014] As used herein, "about" will be understood by persons of ordinary skill in the art and will vary to some extent depending upon the context in which it is used. If there are uses of the term which are not clear to persons of ordinary skill in the art, given the context in which it is used, "about" will mean up to plus or minus 10% of the particular term.

[0015] The use of the terms "a" and "an" and "the" and similar referents in the context of describing the elements (especially in the context of the following claims) are to be construed

to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (*e.g.*, "such as") provided herein, is intended merely to better illuminate the embodiments and does not pose a limitation on the scope of the claims unless otherwise stated. No language in the specification should be construed as indicating any non-claimed element as essential.

[0016] As used herein, the term "catalyst" or "catalyst composition" or "catalyst material" refers to a material that promotes a reaction.

[0017] As used herein, the term "fluid catalytic cracking" or "FCC" refers to a conversion process in petroleum refineries wherein high-boiling, high-molecular weight hydrocarbon fractions of petroleum crude oils are converted to more valuable gasoline, olefinic gases, and other products.

[0018] "Cracking conditions" or "FCC conditions" refers to typical FCC process conditions. Typical FCC processes are conducted at reaction temperatures of 450° to 650° C with catalyst regeneration temperatures of 600° to 850° C. Hot regenerated catalyst is added to a hydrocarbon feed at the base of a rise reactor. The fluidization of the solid catalyst particles may be promoted with a lift gas. The catalyst vaporizes and superheats the feed to the desired cracking temperature. During the upward passage of the catalyst and feed, the feed is cracked, and coke deposits on the catalyst. The coked catalyst and the cracked products exit the riser and enter a solid-gas separation system, e.g., a series of cyclones, at the top of the reactor vessel. The cracked products are fractionated into a series of products, including gas, gasoline, light gas oil, and heavy cycle gas oil. Some heavier hydrocarbons may be recycled to the reactor.

[0019] As used herein, the term "fluid catalytic cracking catalyst" or "FCC catalyst" refers to an active component of microspheres containing zeolite Y. An FCC catalyst containing zeolite Y is the base component for catalytically converting the high-boiling, high-molecular weight hydrocarbon fractions of petroleum crude oils into more valuable products.

[0020] As used herein, the term "fluid catalytic cracking additive" or "FCC additive" refers to an active component of microspheres that are composed of calcined kaolin with low surface area, with and without zeolite, such as ZSM-5. An FCC additive is generally used together with an FCC catalyst to change the product distribution as compared to an FCC catalyst alone. For example, an FCC additive containing ZSM-5 may be used to change the cracking product distribution to lighter olefins, such as propylene. An FCC catalyst and an FCC additive are generally separate microsphere particles to be used in the FCC process as blends, with the FCC additive as the minor component of no more than 30 wt% in the blends. In some embodiments, an FCC catalyst component with zeolite Y and an additive component with ZSM-5 may be included in the same microsphere particles.

[0021] As used herein, the term "feed" or "feedstock" refers to that portion of crude oil that has a high boiling point and a high molecular weight. In FCC processes, a hydrocarbon feedstock is injected into the riser section of a FCC unit, where the feedstock is cracked into lighter, more valuable products upon contacting hot catalyst circulated to the riser-reactor from a catalyst regenerator.

[0022] As used herein, the term "zeolite" refers to is a crystalline aluminosilicate with a framework based on an extensive three-dimensional network of oxygen ions and has a substantially uniform pore distribution.

[0023] As used herein, a "colloidal oxide binder" refers to a suspension of evenly dispersed microscopic insoluble oxide particles in a solution. The colloidal oxide dispersions are generally produced by the hydrolysis of a metallic salt or by the peptization of the hydrous oxide of a metal. Non-limiting illustrative examples of the evenly dispersed microscopic insoluble oxide particles include silica and alumina.

[0024] As discussed above, FCC catalysts or catalyst blends must be attrition resistant. Thus, any FCC additive that is part of an FCC catalyst blend must also exhibit attrition resistance. Improving attrition resistance in FCC additives can minimize catalyst loss and fresh catalyst addition. Thus, there is a need for FCC additives with improved attrition resistance.

[0025] It has been unexpectedly found that the addition of boron to a colloidal oxide binder provides FCC additives with improved attrition resistance as measured by Air Jet abrasion. The boron-containing FCC additives exhibit an improved attrition resistance of about 10% to

about 50% compared to an FCC additive without boron.

[0026] In one aspect, disclosed herein is a method for improving attrition resistance in an FCC additive. The method may include adding a solution of a boron-containing compound to a composition that may include a zeolite and a colloidal oxide binder.

[0027] The solution of a boron-containing compound may be prepared by dissolving a boron-containing compound in water. Non-limiting illustrative examples of the boron-containing compound include an alkaline borate, boric acid, ammonium borate, or a combination of two or more thereof. In some embodiments, the boron-containing compound may include an alkaline borate. In some embodiments, the boron-containing compound may include boric acid. In some embodiments, the boron-containing compound may include ammonium borate. In some embodiments, the boron-containing compound may include a combination of two or more of an alkaline borate, boric acid, or an ammonium borate.

[0028] In some embodiments, in addition to the zeolite and colloidal oxide binder, the composition may also include hydrous kaolin. In some embodiments, in addition to the zeolite and colloidal oxide binder, the composition may also include alpha alumina. In some embodiments, the composition may also include both hydrous kaolin and alpha alumina.

[0029] The FCC additive used in the methods may include about 0.5 wt% to about 3 wt% of the boron-containing compound. In some embodiments, the FCC additive may include about 0.5 wt% to about 2.5 wt% of the boron-containing compound. In some embodiments, the FCC additive may include about 0.8 wt% to about 2.5 wt% of the boron-containing compound. In some embodiments, the FCC additive may include about 0.8 wt% to about 2 wt% of the boron-containing compound. In some embodiments, the FCC additive may include about 0.5 wt%, 0.6 wt%, 0.7 wt%, 0.8 wt%, 0.9 wt%, 1.0 wt%, 1.5 wt%, 2.0 wt%, or about 2.5 wt% of the boron-containing compound.

[0030] The FCC additive of the method disclosed herein may also include a zeolite. Non-limiting illustrative examples of such zeolites include zeolite socony mobil-5 (ZSM-5), ZSM-5 modified with other elements such as phosphorous, Beta zeolite, Ferrierite, Chabazite and IM-5 zeolite. In some embodiments, the zeolite may include ZSM-5 and/or Beta zeolite.

[0031] In some embodiments, the FCC additive may include about 30 wt% to about 70 wt% of the zeolite. In some embodiments, the FCC additive may include about 40 wt% to

about 70 wt% of the zeolite. In some embodiments, the FCC additive may include about 50 wt% to about 70 wt% of the zeolite. In some embodiments, the FCC additive may include about 40 wt% to about 60 wt% of the zeolite. In some embodiments, the FCC additive may include about 40 wt%, 45 wt%, 50 wt% , 55 wt%, 60 wt%, or 65 wt% of the zeolite.

[0032] The FCC additive of the method disclosed herein may also include a colloidal oxide binder. Non-limiting illustrative examples of a colloidal oxide binder include colloidal silica, colloidal alumina, and a mixture of colloidal silica and colloidal alumina, colloidal zinc oxide colloidal tin oxide and colloidal zirconia oxide. In some embodiments, the colloidal oxide binder may include colloidal silica. In some embodiments, the colloidal oxide binder may include colloidal alumina. In some embodiments, the colloidal oxide binder may include a mixture of colloidal silica and colloidal alumina.

[0033] The colloidal alumina may be prepared by peptizing boehmite alumina with a monoprotic acid or hydrolysis of aluminum metal. In some embodiments, the monoprotic acid may include formic acid, chloric acid and/or nitric acid.

[0034] The FCC additive used in the method disclosed herein may further include hydrous kaolin. In some embodiments, the FCC additive may include about 5 wt% to about 40 wt% of the hydrous kaolin. In some embodiments, the FCC additive may include about 10 wt% to about 35 wt% of the hydrous kaolin. In some embodiments, the FCC additive may include about 10 wt% to about 30 wt% of the hydrous kaolin. In some embodiments, the FCC additive may include about 10 wt%, 15 wt%, 20 wt%, 25 wt%, 30 wt%, or 35 wt% of the hydrous kaolin.

[0035] The FCC additive used in the method disclosed herein may further include alpha alumina. In some embodiments, the FCC additive may include about 0.1 wt% to about 10.0 wt% of the alpha alumina. In some embodiments, the FCC additive may include about 1.0 wt% to about 9.0 wt% of the alpha alumina. In some embodiments, the FCC additive may include about 4.0 wt% to about 8.0 wt% of the alpha alumina. In some embodiments, the FCC additive may include about 5.0 wt% to about 8.0 wt% of the alpha alumina. In some embodiments, the FCC additive may include about 5.0 wt%, 5.5 wt%, 6.0 wt%, 6.5 wt%, 7.0 wt%, 7.5 wt%, 8.0 wt%, or 8.5 wt% of the alpha alumina.

[0036] The FCC additive used in the method disclosed herein may further include additional added alumina, such as gamma alumina or crystalline boehmite. In some

embodiments, the FCC additive may include about 0.1 wt% to about 30.0 wt% of the added alumina.

[0037] As discussed above, the method disclosed herein improves the attrition resistance of an FCC additive. In some embodiments, the attrition resistance of the FCC additive may be improved by about 10% to about 50% compared to an FCC additive without boron, as measured by Air Jet abrasion. In some embodiments, the attrition resistance of the FCC additive may be improved by about 10% to about 40% compared to an FCC additive without boron, as measured by Air Jet abrasion. In some embodiments, the attrition resistance of the FCC additive may be improved by about 10%, 20%, 25%, 30%, 33%, 35%, or 40% compared to an FCC additive without boron, as measured by Air Jet abrasion.

[0038] Methods of measuring the attrition resistance of an FCC additive or an FCC catalyst using Air Jet abrasion is well-known in the art. Air jet abrasion is a technique that provides information concerning the ability of a powdered catalyst to resist particle size reduction during use in a fluidized environment, typically the ASTM D5757 method. In some embodiments, the FCC additive may exhibit an Air Jet attrition rate of about 1%/hr to about 5%/hr. In some embodiments, the FCC additive may exhibit an Air Jet attrition rate of about 2%/hr to about 4.5%/hr. In some embodiments, the FCC additive may exhibit an Air Jet attrition rate of about 2%/hr, 2.3%/hr, 2.5%/hr, 2.7%/hr, 3.0%/hr, 3.5%/hr, 3.6%/hr, 4.0%/hr, 4.2%/hr, 4.4%/hr, 4.6%/hr, 4.8%/hr, or 5.0%/hr.

[0039] In some embodiments, the method disclosed herein may also include spray-drying the FCC additive into microspheres.

Fluid Catalytic Cracking Additives

[0040] In one aspect, provided herein is an FCC additive that may include a boron-containing compound, a zeolite, and a colloidal oxide binder.

[0041] In another aspect, disclosed herein is an FCC additive prepared by dissolving a boron-containing compound in water to prepare an aqueous solution; mixing a zeolite and a colloidal oxide binder to form a slurry; adding the aqueous solution to the slurry to form a mixture; adding phosphoric acid to the mixture to form an acidified mixture; and spray-drying the acidified mixture to form microspheres of the fluid catalytic cracking additive.

[0042] In some embodiments, the boron-containing compound is soluble in water. Non-limiting illustrative examples of the boron-containing compound include an alkaline borate, boric acid, ammonium borate, or a combination of two or more thereof. In some embodiments, the boron-containing compound may include an alkaline borate. In some embodiments, the boron-containing compound may include boric acid. In some embodiments, the boron-containing compound may include ammonium borate. In some embodiments, the boron-containing compound may include a combination of two or more of an alkaline borate, boric acid, or an ammonium borate.

[0043] In some embodiments, the FCC additive may include about 0.5 wt% to about 3 wt% of the boron-containing compound. In some embodiments, the FCC additive may include about 0.5 wt% to about 2.5 wt% of the boron-containing compound. In some embodiments, the FCC additive may include about 0.8 wt% to about 2.5 wt% of the boron-containing compound. In some embodiments, the FCC additive may include about 0.8 wt% to about 2 wt% of the boron-containing compound. In some embodiments, the FCC additive may include about 0.5 wt%, 0.6 wt%, 0.7 wt%, 0.8 wt%, 0.9 wt%, 1.0 wt%, 1.5 wt%, 2.0 wt%, or about 2.5 wt% of the boron-containing compound.

[0044] The FCC additive disclosed herein may include a zeolite. Non-limiting illustrative examples of a zeolite include zeolite socony mobil-5 (ZSM-5), ZSM-5 modified with other elements such as phosphorous, Beta zeolite, Ferrierite, Chabazite and IM-5 zeolite. In some embodiments, the zeolite may include ZSM-5 and/or Beta zeolite.

[0045] In some embodiments, the FCC additive may include about 30 wt% to about 70 wt% of the zeolite. In some embodiments, the FCC additive may include about 40 wt% to about 70 wt% of the zeolite. In some embodiments, the FCC additive may include about 50 wt% to about 70 wt% of the zeolite. In some embodiments, the FCC additive may include about 40 wt% to about 60 wt% of the zeolite. In some embodiments, the FCC additive may include about 40 wt%, 45 wt%, 50 wt% , 55 wt%, 60 wt%, or 65 wt% of the zeolite.

[0046] The FCC additive disclosed herein may include a colloidal oxide binder. Non-limiting illustrative examples of a colloidal oxide binder include colloidal silica, colloidal alumina, and a mixture of colloidal silica and colloidal alumina, colloidal zinc oxide, colloidal tin oxide and colloidal zirconia oxide. In some embodiments, the colloidal oxide binder may include colloidal silica. In some embodiments, the colloidal oxide binder may

include colloidal alumina. In some embodiments, the colloidal oxide binder may include a mixture of colloidal silica and colloidal alumina.

[0047] In some embodiments, the colloidal alumina may be prepared by peptizing boehmite alumina with a monoprotic acid or hydrolysis of aluminum metal. In some embodiments, the monoprotic acid may include formic acid, chloric acid and/or nitric acid.

[0048] The FCC additive disclosed herein may further include hydrous kaolin. In some embodiments, the FCC additive may include about 5 wt% to about 40 wt% of the hydrous kaolin. In some embodiments, the FCC additive may include about 10 wt% to about 35 wt% of the hydrous kaolin. In some embodiments, the FCC additive may include about 10 wt% to about 30 wt% of the hydrous kaolin. In some embodiments, the FCC additive may include about 10 wt%, 15 wt%, 20 wt%, 25 wt%, 30 wt%, or 35 wt% of the hydrous kaolin.

[0049] The FCC additive disclosed herein may further include alpha alumina. In some embodiments, the FCC additive may include about 0.1 wt% to about 10.0 wt% of the alpha alumina. In some embodiments, the FCC additive may include about 1.0 wt% to about 9.0 wt% of the alpha alumina. In some embodiments, the FCC additive may include about 4.0 wt% to about 8.0 wt% of the alpha alumina. In some embodiments, the FCC additive may include about 5.0 wt% to about 8.0 wt% of the alpha alumina. In some embodiments, the FCC additive may include about 5.0 wt%, 5.5 wt%, 6.0 wt%, 6.5 wt%, 7.0 wt%, 7.5 wt%, 8.0 wt%, or 8.5 wt% of the alpha alumina.

[0050] The FCC additive disclosed herein may further include additional added alumina, such as gamma alumina or crystalline boehmite. In some embodiments, the FCC additive may include about 0.1 wt% to about 30.0 wt% of the added alumina.

[0051] The FCC additive disclosed herein exhibit improved attrition resistance properties. In some embodiments, the attrition resistance of the FCC additive may be improved by about 10% to about 50% compared to an FCC additive without boron, as measured by Air Jet abrasion. In some embodiments, the attrition resistance of the FCC additive may be improved by about 10% to about 40% compared to an FCC additive without boron, as measured by Air Jet abrasion. In some embodiments, the attrition resistance of the FCC additive may be improved by about 10%, 20%, 25%, 30%, 33%, 35%, or 40% compared to an FCC additive without boron, as measured by Air Jet abrasion.

[0052] In some embodiments, the FCC additive disclosed herein may exhibit an Air Jet attrition rate of about 1%/hr to about 5%/hr. In some embodiments, the FCC additive may exhibit an Air Jet attrition rate of about 2%/hr to about 4.5%/hr. In some embodiments, the FCC additive may exhibit an Air Jet attrition rate of about 2%/hr, 2.3%/hr, 2.5%/hr, 2.7%/hr, 3.0%/hr, 3.5%/hr, 3.6%/hr, 4.0%/hr, 4.2%/hr, 4.4%/hr, 4.6%/hr, 4.8%/hr, or 5.0%/hr.

[0053] In some embodiments, the FCC additive disclosed herein is a microsphere. In some embodiments, the FCC additive is spray-dried into microspheres.

Methods of Preparing

[0054] In one aspect, disclosed herein is a method of preparing an FCC additive as described above. The method may include dissolving a boron-containing compound as described above in water to prepare an aqueous solution; mixing a zeolite as described above and a colloidal oxide binder as described above to form a slurry; adding the aqueous solution to the slurry to form a mixture; adding phosphoric acid to the mixture; and spray-drying the mixture to form microspheres of the FCC additive.

Methods of Use

[0055] In one aspect, disclosed herein is a method of increasing the yield for light olefins in a fluid catalytic cracking process. The method may include mixing an FCC catalyst with any of the FCC additives described above.

[0056] The present invention, thus generally described, will be understood more readily by reference to the following examples, which are provided by way of illustration and are not intended to be limiting of the present invention.

EXAMPLES

Example 1.

Comparative Example 1

[0057] An FCC additive was prepared in a similar way as described in Example 1 of U.S. Patent No 7,547,813, the entirety of which is incorporated herein by reference. ZSM-5 having a SiO_2/Al_2O_3 molar ratio of 28 was slurried with water and milled to a particle size of 90 % < 3 micron to obtain a slurry that was about 30 wt% solids. The FCC additive was

prepared by mixing a 70 wt% hydrous kaolin slurry with a 30 wt% ZSM-5 slurry and a mixture of aluminas, including alpha alumina and peptized boehmite. This mixture was then spray dried with the addition of phosphoric acid (28 wt%) via an in-line mixer just prior to entering the spray dryer. The contact time of the phosphoric acid and kaolin/ZSM-5 zeolite/aluminas was typically less than 20 seconds. The spray dried additive has a composition listed in Table 1.

Example 1

[0058] ZSM-5 having a SiO_2/Al_2O_3 molar ratio of 28 was slurried with water and milled to a particle size of 90 % < 3 micron to obtain a slurry that was about 30 wt% solids. The FCC additive was prepared by mixing a 70 wt% hydrous kaolin slurry with a 30 wt% ZSM-5 slurry and a mixture of aluminas, including alpha alumina and peptized boehmite, and a 1 wt% boric acid solution by dissolving boric acid in hot water. This mixture was then spray dried with addition of phosphoric acid (28 wt%) via an in-line mixer just prior to entering the spray dryer. The contact time of the phosphoric acid and kaolin/ZSM-5 zeolite/aluminas/Boric acid was typically less than 20 seconds. The spray dried additive has a composition listed in Table 1. The attrition resistance was improved by 27% as the Airjet attrition rate (AJAR) was lowered from 3.25%/hr to 2.36%/hr.

Table 1: Compositional Data for Comparative Example 1 and Example 1

	Comparative Example 1	Example 1
ZSM-5, wt%	40	40
Total P_2O_5, wt%	12.8	12.7
Peptized Al_2O_3, wt%	6.5	6.5
Alpha Al_2O_3, wt%	8.5	7.5
Hydrous kaolin, wt%	32.2	32.3
B_2O_3, wt%		~1
Airjet attrition rate %/hr	3.25	2.36

Example 2.

Comparative Example 2

[0059] An FCC additive was prepared in a similar way as described in Comparative Example 1. ZSM-5 having a SiO_2/Al_2O_3 molar ratio of 28 was slurried with water and milled to a particle size of 90 % < 3 micron to obtain a slurry that was about 30 wt% solids. The

FCC additive was prepared by mixing a 70 wt% hydrous kaolin slurry with a 30 wt% ZSM-5 slurry and a mixture of aluminas, including alpha alumina and peptized boehmite. This mixture was then spray dried with addition of phosphoric acid (28 wt%) via an in-line mixer just prior to entering the spray dryer. The contact time of the phosphoric acid and kaolin/ZSM-5 zeolite/aluminas was typically less than 20 seconds. The spray dried additive has a composition listed in Table 2.

Example 2

[0060] ZSM-5 having a SiO_2/Al_2O_3 molar ratio of 28 was slurried with water and milled to a particle size of 90 % < 3 micron to obtain a slurry that was about 30 wt% solids. The FCC additive was prepared by mixing a 70 wt% hydrous kaolin slurry with a 30 wt% ZSM-5 slurry and a mixture of aluminas, including alpha alumina and peptized boehmite, and a 1 wt% boric acid solution by dissolving boric acid in hot water. This mixture was then spray dried with addition of phosphoric acid (28 wt%) via an in-line mixer just prior to entering the spray dryer. The contact time of the phosphoric acid and kaolin/ZSM-5 zeolite/aluminas/Boric acid was typically less than 20 seconds. The spray dried additive has a composition listed in Table 2. The attrition resistance was improved by 33% as the Airjet attrition rate (AJAR) was lowered from 5.38%/hr to 3.6%/hr.

Table 2: Compositional Data for Comparative Example 2 and Example 2

	Comparative Example 2	Example 2
ZSM-5, wt%	50	50
Total P_2O_5, wt%	12.7	13.0
Peptized Al_2O_3, wt%	7	7
Alpha Al_2O_3, wt%	8	8
Hydrous kaolin, wt%	22.3	21.2
B_2O_3, wt%		0.8
Airjet attrition rate %/hr	5.38	3.60

Example 3.

Comparative Example 3

[0061] An FCC additive was prepared in a similar way as described in Comparative Example 1. ZSM-5 having a SiO_2/Al_2O_3 molar ratio of 28 was slurried with water and milled to a particle size of 90 % < 3 micron to obtain a slurry that was about 30 wt%. The FCC

additive was prepared by mixing a 70 wt% hydrous kaolin slurry with a 30 wt% ZSM-5 slurry and a mixture of aluminas, including alpha alumina and peptized boehmite. This mixture was then spray dried with addition of phosphoric acid (28 wt%) via an in-line mixer just prior to entering the spray dryer. The contact time of the phosphoric acid and kaolin/ZSM-5 zeolite/aluminas was typically less than 20 seconds. The spray dried additive has a composition listed in Table 3.

Example 3

[0062] ZSM-5 having a SiO_2/Al_2O_3 molar ratio of 28 was slurried with water and milled to a particle size of 90 % < 3 micron to obtain a slurry that was about 30 wt% solids. The FCC additive was prepared by mixing a 70 wt% hydrous kaolin slurry with a 30 wt% ZSM-5 slurry and a mixture of aluminas, including alpha alumina and peptized boehmite, and a 1 wt% boric acid solution by dissolving boric acid in hot water. This mixture was then spray dried with addition of phosphoric acid (28 wt%) via an in-line mixer just prior to entering the spray dryer. The contact time of the phosphoric acid and kaolin/ZSM-5 zeolite/aluminas/Boric acid was typically less than 20 seconds. The spray dried additive has a composition listed in Table 3. The attrition resistance was improved by 24%.

Table 3: Compositional Data for Comparative Example 3 and Example 3

	Comparative Example 3	Example 3
ZSM-5, wt%	60	60
Total P_2O_5, wt%	13.0	13.2
Peptized Al_2O_3, wt%	8	8
Alpha Al_2O_3, wt%	7	7
Hydrous kaolin, wt%	12	10.9
B_2O_3, wt%		0.9
Airjet attrition rate %/hr	6.13	4.63

Example 4.

Comparative Example 4

[0063] A phosphorus-treated ZSM-5 having a SiO_2/Al_2O_3 molar ratio of 28 was slurried with water and milled to a particle size of 90 % < 3 micron to obtain a slurry that was about 30 wt% solids. The phosphorus-treatment of ZSM-5 was described in U.S. Patent Application Publication No. 2014/0206526, the entirety of which is incorporated herein by

reference. The FCC additive was prepared by mixing a 70 wt% hydrous kaolin slurry with a 30 wt% ZSM-5 slurry and a mixture of aluminas, including alpha alumina and peptized boehmite, and a colloidal silica Nalco 2326. This mixture was then spray dried in a spray dryer. The spray dried additive has a composition listed in Table 4.

Example 4

[0064] A phosphorus treated ZSM-5 having a SiO_2/Al_2O_3 molar ratio of 28 was slurried with water and milled to a particle size of 90 % < 3 micron to obtain a slurry that was about 30 wt% solids. The phosphorus-treatment of ZSM-5 was described in U.S. Patent Application Publication No. 2014/0206526. The FCC additive was prepared by mixing a 70 wt% hydrous kaolin slurry with a 30 wt% ZSM-5 slurry and a mixture of aluminas, including alpha alumina and peptized boehmite, a colloidal silica Nalco 2326, and a 1 wt% boric acid solution by dissolving boric acid in hot water. This mixture was then spray dried in a spray dryer. The spray dried additive has a composition listed in Table 4. The attrition resistance was improved by 10%.

Table 4: Compositional Data for Comparative Example 4 and Example 4

	Comparative Example 4	Example 4
ZSM-5, wt%	40	40
Total P_2O_5, wt%	2.0	2.0
Peptized Al_2O_3, wt%	6.5	6.5
Alpha Al_2O_3, wt%	8.5	6.5
Hydrous kaolin, wt%	30	30
Colloidal SiO_2	15	15
B_2O_3, wt%		~2
Airjet attrition rate %/hr	5.34	4.81

Example 5.

[0065] The catalytic testing of the spray dried FCC additives described in Comparative Example 1 and Example 1 were performed on an Advanced Cracking Evaluation (ACE) fluidized-bed hydrocarbon cracking reactor using a resid feed. The catalyst blend was comprised of 65 wt% FCC base catalyst, 15 wt% ZSM-5 additive, and 20% high temperature calcined kaolin inert microspheres designated as MS3. The base catalyst was first impregnated with 2000 ppm Ni and 3000 ppm V before blending with the ZSM-5 additive and MS3. The catalyst blend was deactivated following a cyclic propylene steaming protocol

prior to testing. The results at a constant 75% conversion are presented in Table 5. The results demonstrate that the boron addition to the FCC additive increases the light olefin (propylene and butenes) yields compared to the FCC additive without boron.

Table 5: Light Olefin Yields Based on Comparative Example 1 and Example 1

	Comparative Example 1	Example 1
Ethylene, wt%	1.28	1.38
Propylene, wt%	11.02	11.62
Butenes, wt%	10.27	10.83
Total C2-, wt%	3.07	3.04
LPG, wt%	27.59	28.74
Gasoline, wt%	37.72	36.82
LCO, wt%	15.17	15.20
HCO, wt%	9.83	9.80
Coke, wt%	6.62	6.40
Cat/Oil, wt%	4.47	4.57

[0066] Para. 1. A method for improving attrition resistance in a fluid catalytic cracking (FCC) additive, the method comprising adding a solution of a boron-containing compound to a composition comprising a zeolite and a colloidal oxide binder.

[0067] Para. 2. The method of Para. 1, wherein the solution is prepared by dissolving a boron-containing compound in water.

[0068] Para. 3. The method of Para. 2, wherein the boron-containing compound is an alkaline borate, boron trioxide, boric acid, or ammonium borate.

[0069] Para. 4. The method of any one of Paras. 1-3, wherein the boron-containing compound comprises about 0.5 wt% to about 3 wt% of the FCC additive.

[0070] Para. 5. The method of Para. 4, wherein the boron-containing compound comprises about 0.8 wt% to about 2 wt% of the FCC additive.

[0071] Para. 6. The method of any one of Paras. 1-5, wherein the zeolite comprises about 30 wt% to about 70 wt% of the FCC additive.

[0072] Para. 7. The method of any one of Paras. 1-6, wherein the zeolite comprises about 40 wt% to about 60 wt% of the FCC additive.

[0073] Para. 8. The method of any one of Paras. 1-7, wherein the zeolite comprises about 40 wt%, 50 wt% , or 60 wt% of the FCC additive.

[0074] Para. 9. The method of any one of Paras. 1-8, wherein the zeolite comprises ZSM-5.

[0075] Para. 10. The method of any one of Paras. 1-9, wherein the composition comprising a zeolite and a colloidal oxide binder further comprises hydrous kaolin.

[0076] Para. 11. The method of Para. 10, wherein the hydrous kaolin comprises about 5 wt% to about 40 wt% of the FCC additive.

[0077] Para. 12. The method of Para. 10 or 11, wherein the hydrous kaolin comprises about 10 wt% to about 30 wt% of the FCC additive.

[0078] Para. 13. The method of any one of Paras. 1-12, wherein the colloidal oxide binder comprises colloidal silica, colloidal alumina, or a mixture of colloidal silica and colloidal alumina.

[0079] Para. 14. The method of Para. 13, wherein the colloidal alumina is prepared by peptizing boehmite alumina with a monoprotic acid.

[0080] Para. 15. The method of Para. 14, wherein the monoprotic acid is formic acid.

[0081] Para. 16. The method of any one of Paras. 1-15, wherein the composition comprising a zeolite and a colloidal oxide binder further comprises alpha alumina.

[0082] Para. 17. The method of Para. 16, wherein the alpha alumina comprises about 0.1 wt% to about 10.0 wt% of the FCC additive.

[0083] Para. 18. The method of any one of Paras. 1-17, wherein the attrition resistance of the FCC additive is improved by about 10% to about 50% compared to an FCC additive without boron, as measured by Air Jet abrasion.

[0084] Para. 19. The method of any one of Paras. 1-18, wherein the FCC additive exhibits an Air Jet attrition rate of about 1%/hr to about 5%/hr.

[0085] Para. 20. The method of any one of Paras. 1-19, wherein the FCC additive exhibits an Air Jet attrition rate of about 2%/hr to about 4.5%/hr.

[0086] Para. 21. The method of any one of Paras. 1-20, wherein the FCC additive is spray-dried to form microspheres.

[0087] Para. 22. A method of preparing a fluid catalytic cracking additive, the method comprising dissolving a boron-containing compound in water to prepare an aqueous solution; mixing a zeolite and a colloidal oxide binder to form a slurry; adding the aqueous solution to the slurry to form a mixture; adding phosphoric acid to the mixture; and spray-drying the mixture to form microspheres of the fluid catalytic cracking additive.

[0088] Para. 23. A fluid catalytic cracking additive prepared by: dissolving a boron-containing compound in water to prepare an aqueous solution; mixing a zeolite and a colloidal oxide binder to form a slurry; adding the aqueous solution to the slurry to form a mixture; adding phosphoric acid to the mixture to form an acidified mixture; and spray-drying the acidified mixture to form microspheres of the fluid catalytic cracking additive.

[0089] Para. 24. A fluid catalytic cracking (FCC) additive comprising a boron-containing compound, a zeolite, and a colloidal oxide binder.

[0090] Para. 25. The FCC additive of Para. 24, wherein the boron-containing compound is soluble in water.

[0091] Para. 26. The FCC additive of Para. 24 or 25, wherein the boron-containing compound is an alkaline borate, boric acid or ammonium borate.

[0092] Para. 27. The FCC additive of any one of Paras. 24-26, wherein the boron-containing compound comprises about 0.5 wt% to about 3 wt% of the FCC additive.

[0093] Para. 28. The FCC additive of any one of Paras. 24-27, wherein the boron-containing compound comprises about 0.8 wt% to about 2 wt% of the FCC additive.

[0094] Para. 29. The FCC additive of any one of Paras. 24-28, wherein the zeolite comprises about 30 wt% to about 70 wt% of the FCC additive.

[0095] Para. 30. The FCC additive of any one of Paras. 24-29, wherein the zeolite comprises about 40 wt% to about 60 wt% of the FCC additive.

[0096] Para. 31. The FCC additive of any one of Paras. 24-30, wherein the zeolite comprises about 40 wt%, 50 wt% , or 60 wt% of the FCC additive.

[0097] Para. 32. The FCC additive of any one of Paras. 24-31, wherein the zeolite comprises ZSM-5.

[0098] Para. 33. The FCC additive of any one of Paras. 24-32, further comprising hydrous kaolin.

[0099] Para. 34. The FCC additive of Para. 33, wherein the hydrous kaolin comprises about 5 wt% to about 40 wt% of the FCC additive.

[0100] Para. 35. The FCC additive of any one of Paras. 33-34, wherein the hydrous kaolin comprises about 10 wt% to about 30 wt% of the FCC additive.

[0101] Para. 36. The FCC additive of any one of Paras. 24-35, wherein the colloidal oxide binder comprises colloidal silica, colloidal alumina, or a mixture of colloidal silica and colloidal alumina.

[0102] Para. 37. The FCC additive of Para. 36, wherein the colloidal alumina is prepared by peptizing boehmite alumina with a monoprotic acid.

[0103] Para. 38. The FCC additive of Para. 37, wherein the monoprotic acid is formic acid.

[0104] Para. 39. The FCC additive of any one of Paras. 24-38, wherein the FCC additive further comprises alpha alumina.

[0105] Para. 40. The FCC additive of Para. 39, wherein the alpha alumina comprises about 0 wt% to about 10.0 wt% of the FCC additive.

[0106] Para. 41. The FCC additive of any one of Paras. 24-40, wherein the FCC additive further comprises phosphorous oxide.

[0107] Para. 42. The FCC additive of Para. 41, wherein the phosphorous oxide comprises about 0 wt% to about 20.0 wt% of the FCC additive.

[0108] Para. 43. The FCC additive of any one of Paras. 24-42, wherein the attrition resistance of the FCC additive is improved by about 10% to about 50% compared to an FCC additive without boron, as measured by Air Jet abrasion.

[0109] Para. 44. The FCC additive of any one of Paras. 24-43, wherein the FCC additive exhibits an Air Jet attrition rate of about 1%/hr to about 5%/hr.

[0110] Para. 45. The FCC additive of any one of Paras. 24-43, wherein the FCC additive exhibits an Air Jet attrition rate of about 2%/hr to about 4.5%/hr.

[0111] Para. 46. The FCC additive of any one of Paras. 24-45, wherein the FCC additive is a microsphere.

[0112] Para. 47. A method of increasing the yield for light olefins in a fluid catalytic cracking process, the method comprising mixing a fluid catalytic cracking catalyst with the fluid catalytic cracking additive of any one of Paras. 23-46.

[0113] While certain embodiments have been illustrated and described, it should be understood that changes and modifications can be made therein in accordance with ordinary skill in the art without departing from the technology in its broader aspects as defined in the following claims.

[0114] The embodiments, illustratively described herein may suitably be practiced in the absence of any element or elements, limitation or limitations, not specifically disclosed herein. Thus, for example, the terms "comprising," "including," "containing," etc. shall be read expansively and without limitation. Additionally, the terms and expressions employed herein have been used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the claimed technology. Additionally, the phrase "consisting essentially of" will be understood to include those elements specifically recited and those additional elements that do not materially affect the basic and novel characteristics of the claimed technology. The phrase "consisting of" excludes any element not specified.

[0115] The present disclosure is not to be limited in terms of the particular embodiments described in this application. Many modifications and variations can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. Functionally equivalent methods and compositions within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods, reagents,

compounds compositions or biological systems, which can of course vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

[0116] In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

[0117] As will be understood by one skilled in the art, for any and all purposes, particularly in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, *etc.* As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third and upper third, *etc.* As will also be understood by one skilled in the art all language such as "up to," "at least," "greater than," "less than," and the like, include the number recited and refer to ranges which can be subsequently broken down into subranges as discussed above. Finally, as will be understood by one skilled in the art, a range includes each individual member.

[0118] All publications, patent applications, issued patents, and other documents referred to in this specification are herein incorporated by reference as if each individual publication, patent application, issued patent, or other document was specifically and individually indicated to be incorporated by reference in its entirety. Definitions that are contained in text incorporated by reference are excluded to the extent that they contradict definitions in this disclosure.

[0119] Other embodiments are set forth in the following claims.

WHAT IS CLAIMED IS:

1. A method for improving attrition resistance in a fluid catalytic cracking (FCC) additive, the method comprising adding a solution of a boron-containing compound to a composition comprising a zeolite and a colloidal oxide binder.

2. The method of claim 1, wherein the solution is prepared by dissolving a boron-containing compound in water.

3. The method of claim 2, wherein the boron-containing compound is an alkaline borate, boron trioxide, boric acid, or ammonium borate.

4. The method of any preceding claim, wherein the boron-containing compound comprises about 0.5 wt% to about 3 wt% of the FCC additive.

5. The method of claim 4, wherein the boron-containing compound comprises about 0.8 wt% to about 2 wt% of the FCC additive.

6. The method of any preceding claim, wherein the zeolite comprises about 30 wt% to about 70 wt% of the FCC additive.

7. The method of any preceding claim, wherein the zeolite comprises about 40 wt% to about 60 wt% of the FCC additive.

8. The method of any preceding claim, wherein the zeolite comprises about 40 wt%, 50 wt%, or 60 wt% of the FCC additive.

9. The method of any preceding claim, wherein the zeolite comprises ZSM-5.

10. The method of any preceding claim, wherein the composition comprising a zeolite and a colloidal oxide binder further comprises hydrous kaolin.

11. The method of claim 10, wherein the hydrous kaolin comprises about 5 wt% to about 40 wt% of the FCC additive.

12. The method of claim 10 or 11, wherein the hydrous kaolin comprises about 10 wt% to about 30 wt% of the FCC additive.

13. The method of any preceding claim, wherein the colloidal oxide binder comprises colloidal silica, colloidal alumina, or a mixture of colloidal silica and colloidal alumina.

14. The method of claim 13, wherein the colloidal alumina is prepared by peptizing boehmite alumina with a monoprotic acid.

15. The method of claim 14, wherein the monoprotic acid is formic acid.

16. The method of any preceding claim, wherein the composition comprising a zeolite and a colloidal oxide binder further comprises alpha alumina.

17. The method of claim 16, wherein the alpha alumina comprises about 0.1 wt% to about 10.0 wt% of the FCC additive.

18. The method of any preceding claim, wherein the attrition resistance of the FCC additive is improved by about 10% to about 50% compared to an FCC additive without boron, as measured by Air Jet abrasion.

19. The method of any preceding claim, wherein the FCC additive exhibits an Air Jet attrition rate of about 1%/hr to about 5%/hr.

20. The method of any preceding claim, wherein the FCC additive exhibits an Air Jet attrition rate of about 2%/hr to about 4.5%/hr.

21. The method of any preceding claim, wherein the FCC additive is spray-dried to form microspheres.

22. A method of preparing a fluid catalytic cracking additive, the method comprising:
dissolving a boron-containing compound in water to prepare an aqueous solution;
mixing a zeolite and a colloidal oxide binder to form a slurry;
adding the aqueous solution to the slurry to form a mixture;
adding phosphoric acid to the mixture; and
spray-drying the mixture to form microspheres of the fluid catalytic cracking additive.

23. A fluid catalytic cracking additive prepared by:
dissolving a boron-containing compound in water to prepare an aqueous solution;
mixing a zeolite and a colloidal oxide binder to form a slurry;

adding the aqueous solution to the slurry to form a mixture;

adding phosphoric acid to the mixture to form an acidified mixture; and

spray-drying the acidified mixture to form microspheres of the fluid catalytic cracking additive.

24. A fluid catalytic cracking (FCC) additive comprising a boron-containing compound, a zeolite, and a colloidal oxide binder.

25. The FCC additive of claim 24, wherein the boron-containing compound is soluble in water.

26. The FCC additive of claim 24 or 25, wherein the boron-containing compound is an alkaline borate, boric acid or ammonium borate.

27. The FCC additive of any of claims 24-26, wherein the boron-containing compound comprises about 0.5 wt% to about 3 wt% of the FCC additive.

28. The FCC additive of any of claims 24-27, wherein the boron-containing compound comprises about 0.8 wt% to about 2 wt% of the FCC additive.

29. The FCC additive of any of claims 24-28, wherein the zeolite comprises about 30 wt% to about 70 wt% of the FCC additive.

30. The FCC additive of any of claims 24-29, wherein the zeolite comprises about 40 wt% to about 60 wt% of the FCC additive.

31. The FCC additive of any of claims 24-30, wherein the zeolite comprises about 40 wt%, 50 wt% , or 60 wt% of the FCC additive.

32. The FCC additive of any of claims 24-31, wherein the zeolite comprises ZSM-5.

33. The FCC additive of any of claims 24-32, further comprising hydrous kaolin.

34. The FCC additive of claim 33, wherein the hydrous kaolin comprises about 5 wt% to about 40 wt% of the FCC additive.

35. The FCC additive of any of claims 33-34, wherein the hydrous kaolin comprises about 10 wt% to about 30 wt% of the FCC additive.

36. The FCC additive of any of claims 24-35, wherein the colloidal oxide binder comprises colloidal silica, colloidal alumina, or a mixture of colloidal silica and colloidal alumina.

37. The FCC additive of claim 36, wherein the colloidal alumina is prepared by peptizing boehmite alumina with a monoprotic acid.

38. The FCC additive of claim 37, wherein the monoprotic acid is formic acid.

39. The FCC additive of any of claims 24-38, wherein the FCC additive further comprises alpha alumina.

40. The FCC additive of claim 39, wherein the alpha alumina comprises about 0 wt% to about 10.0 wt% of the FCC additive.

41. The FCC additive of any of claims 24-40, wherein the FCC additive further comprises phosphorous oxide.

42. The FCC additive of claim 41, wherein the phosphorous oxide comprises about 0 wt% to about 20.0 wt% of the FCC additive.

43. The FCC additive of any of claims 24-42, wherein the attrition resistance of the FCC additive is improved by about 10% to about 50% compared to an FCC additive without boron, as measured by Air Jet abrasion.

44. The FCC additive of any of claims 24-43, wherein the FCC additive exhibits an Air Jet attrition rate of about 1%/hr to about 5%/hr.

45. The FCC additive of any of claims 24-43, wherein the FCC additive exhibits an Air Jet attrition rate of about 2%/hr to about 4.5%/hr.

46. The FCC additive of any of claims 24-45, wherein the FCC additive is a microsphere.

47. A method of increasing the yield for light olefins in a fluid catalytic cracking process, the method comprising mixing a fluid catalytic cracking catalyst with the fluid catalytic cracking additive of any one of claims 23-46.