

CATALYST FOR ENHANCED PROPYLENE IN FLUIDIZED CATALYTIC CRACKING

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Field of the Invention

[0001] This invention relates to a catalyst composition for improved production of light olefins. More specifically, this invention relates to a catalyst composition for use in an FCC process for the enhanced production of light olefins, particularly propylene, and methods of using said catalyst.

Background of the Invention

[0002] Conventionally, to produce useful chemicals heavy hydrocarbon fractions, such as vacuum gas oil (VGO), are catalytically cracked with a catalyst in a fluidized cracking process. During this process, the catalyst typically circulates between a catalytic reactor and regenerator. In the catalytic reactor, hydrocarbons come in contact with hot catalysts that have been supplied from the regenerator and the hydrocarbons are cracked to produce gasoline, LPG, and dry gas. Coke is also produced during this process and is deposited on the catalyst. The cracked products are typically then separated from the coked catalyst in cyclone separators. Volatiles are stripped with steam and the coked catalyst is then sent to the regenerator. Regenerated catalyst particles are then recirculated to the reactor.

[0003] The product slate from conventional FCC process primarily consists of gasoline, in addition to light olefins, dry gas and LPG. Light olefins, particularly propylene, are increasingly gaining importance to refiners, as these products can increase refinery profit margins due to their high value. Propylene, which is used in the manufacture of various synthetic materials, particularly materials that are used in food packaging industry and thermoplastics, is in high demand. Additional demand for propylene exists in the area of alkylate production, which is increasingly being used as an additive for high-octane gasoline,

due to environmental concerns raised by the use of olefins-containing FCC gasoline and aromatics-containing catalytically reformed gasoline. Propylene and butylene are the raw materials for the alkylate additive.

[0004] Small pore zeolites from the pentasil zeolite family, such as ZSM-5, have been previously used as catalysts in FCC operations. Additionally, pentasil zeolites have been used as additives in traditional FCC catalysts for the purpose of increasing light olefin yields. Prior art methods, however, suffer from the production of low yields of useful and desired light olefins. Thus, due to the various uses for light olefins, such as propylene, there exists a need for increased production and/or improved efficiency in the production of propylene.

Summary

[0005] Generally, a catalyst for producing enhanced light olefin yields by the fluid catalytic cracking of heavy hydrocarbons is provided.

[0006] In another aspect, an FCC catalyst for increased production of propylene and gasoline from heavy hydrocarbon feedstock is provided. The catalyst includes between 10 and 20% by weight of an ultra-stable Y-type zeolite, between 10 and 20% by weight of a phosphorous modified sub-micron ZSM-5, between 20 and 30% by weight of a pseudoboehmite alumina, and between 30 and 40% by weight kaolin.

[0007] In certain embodiments, the phosphorous modified sub-micron ZSM-5 has a crystal size of less than 3 microns. In certain embodiments, the phosphorous modified sub-micron ZSM-5 catalyst has a silica to alumina ratio in the range of between 1:2 and 1:4. In certain embodiments, the phosphorous modified sub-micron ZSM-5 catalyst includes between 5 and 10% by weight phosphorous. In certain embodiments, the pseudoboehmite alumina is peptized.

[0008] In one aspect, an FCC catalyst for enhanced production of light olefins from heavy hydrocarbon feedstock is provided. The catalyst includes: between 10 and 20% by weight of an ultra-stable Y-type zeolite; between 10 and 20% by weight of a pentasil zeolite; between 20 and 30% by weight of a binder material; and between 30 and 40% by weight clay filler material.

[0009] In certain embodiments, the pentasil zeolite is phosphorous modified sub-micron ZSM-5. In certain embodiments, the binder material is a pseudoboehmite alumina. In certain embodiments, the clay filler material is kaolin.

[0010] In another aspect, a process for the fluid catalytic cracking of a heavy hydrocarbon feedstock is provided. The process includes supplying a heavy hydrocarbon feedstock to the reaction zone of an FCC reactor and contacting the heavy hydrocarbon feedstock with a catalyst, the catalyst including between 10 and 20% by weight of a phosphorous modified sub-micron ZSM-5, between 10 and 20% by weight of an ultra-stable Y-type zeolite, between 20 and 30% by weight of a pseudoboehmite alumina, and between 20 and 40% by weight kaolin. The process further includes the step of maintaining the reaction zone such that the outlet temperature of the reaction zone is maintained at a temperature of 550°C, where the catalyst and the heavy hydrocarbon feedstock are contacted for a time sufficient to crack the heavy hydrocarbon feedstock to product an effluent that comprises gasoline and propylene.

[0011] In certain embodiments, the process further includes the step of regenerating the catalyst at a temperature of at least 700°C.

Brief Description of the Drawings

[0012] FIG. 1 shows the particle size distribution of a sub-micron ZSM-5 sample.

[0013] FIG. 2 shows the morphology of a sub-micron ZSM-5 sample as measured by ESEM.

Detailed Description of the Invention

[0014] Although the following detailed description contains many specific details for purposes of illustration, it is understood that one of ordinary skill in the art will appreciate that many examples, variations and alterations to the catalyst and methods described herein are within the scope and spirit of the invention. Accordingly, the exemplary embodiments of the invention described herein are set forth without any loss of generality, and without imposing limitations, on the claimed invention.

[0015] As noted above, in certain embodiments of the present invention, a catalyst composition is provided for enhanced propylene production in a fluid catalytic cracking (FCC) process. In certain embodiments, a catalyst composition is provided for increased propylene and gasoline production from a heavy hydrocarbon stream.

[0016] In one aspect, the present invention is directed to FCC catalysts having both ultra-stable Y-type zeolite and pentasil zeolite as active catalyst components. These FCC catalysts contain both the ultra-stable Y-type zeolite and pentasil zeolite in a shaped particle. These

FCC catalysts share the same matrix. In a preferred embodiment, each particle contains both the ultra-stable Y-type zeolite and the pentasil zeolite generally having a spherical shape.

[0017] In one embodiment of the present invention, FCC catalyst for enhanced production of light olefins from heavy hydrocarbon feedstock includes an ultra-stable Y-type zeolite, a pentasil zeolite, a binder material, and a clay filler material. In certain embodiments, FCC catalyst includes ultra-stable Y-type zeolite, pentasil zeolite, binder material, and clay filler. All percentages by weight refer to the weight of the entire FCC catalyst.

[0018] Ultra-stable Y-type zeolites contain greater ratios of silicon to aluminum than conventional Y-type zeolites. In certain embodiments, the ultra-stable Y-type zeolite acts as a cracking component. In certain embodiments, the ultra-stable Y-type zeolite does not include a rare earth element. In certain embodiments, the ultra-stable Y-type zeolite contains less than 0.2% by weight of a rare earth element, alternately between about 0.1 and 0.2% by weight, alternately between about 0.05 and 0.1% by weight. In certain embodiments, the ultra-stable Y-type zeolite is severely dealuminated. The percentage of ultra-stable Y-type zeolite present in FCC catalyst composition includes, for example, between about 10 and 30% by weight, alternately between about 10 and 20% by weight, alternately between about 15 and 25% by weight. In preferred embodiments the ultra-stable Y-type zeolite has a unit cell size of about 24.56 angstroms.

[0019] In accordance with at least one embodiment of the present invention, FCC catalyst includes a pentasil zeolite. In preferred embodiments, FCC catalyst includes the pentasil zeolite ZSM-5. In the invention, the pentasil zeolite has a sub-micron crystal size. As used herein, the term "sub-micron" refers to a crystal size of the pentasil zeolite having an average particle size distribution below 4000 nm (below 4.0 microns), as shown in FIG. 1. In certain embodiments, FCC catalyst includes a pentasil zeolite having a sub-micron crystal size of between about 0.05 micron and 3 micron. In certain embodiments, the crystal size of the sub-micron ZSM-5 has an average particle size distribution of between about 0.05 and 0.4 microns. One standard morphology of the sub-micron ZSM-5 material is shown in FIG. 2. In certain preferred embodiments, the pentasil zeolite size is less than about 2 microns, alternately less than about 1 micron, alternately less than about 0.40 microns, alternately between about 0.40 microns and about 0.05 microns, alternately between about 0.35 microns and about 0.10 microns. The sub-micron size of the pentasil zeolite increases diffusion of the pentasil zeolite within FCC catalyst. In certain embodiments, the sub-micron ZSM-5 overcomes a diffusion limitation present in catalysts with larger ZSM-5 crystals. In certain

embodiments, the pentasil zeolite, for example, sub-micron ZSM-5, includes a silica to alumina molar ratio of about 1:4, alternately about 1:3, and alternately about 1:2. In certain embodiments, the silica to alumina molar ratio can be between about 1:4 and 1:3; alternately between about 1:3 and 1:2; alternately between about 1:4 and 1:2. The concentration of pentasil zeolite, for example, sub-micron ZSM-5, in FCC catalyst can be between about 10 and 30% by weight, alternately between about 10 and 20% by weight, alternately between about 15 and 25% by weight.

[0020] In certain embodiments, the pentasil zeolite, for example, sub-micron ZSM-5, can be treated with phosphorous-containing compounds, for example, phosphoric acid or mono-ammonium phosphate, to produce phosphorous modified sub-micron ZSM-5. In certain embodiments, the total phosphorous concentration, present as P_2O_5 , of the pentasil zeolite can be between about 5-20% by weight of ZSM-5, alternately between about 5-10% by weight of ZSM-5, alternately between about 10-20% by weight of ZSM-5. The phosphorous-containing compounds are used to stabilize the ZSM-5. No promoter is necessary or used.

[0021] The FCC catalyst useful in this invention is in an absence of any promoter, including acid promoters, solid acid promoters, clay promoters, or otherwise. The FCC catalyst may include an acid component, but the component does not act as a promoter. Instead, it provides some other function, such as stabilization of the catalyst. The FCC catalyst is also used in the absence of an acid dispersed alumina.

[0022] In certain embodiments, FCC catalyst includes a binder material. In certain embodiments, the binder material includes an alumina material. In at least one embodiment, the alumina material is pseudoboehmite. Pseudoboehmite is an alumina oxide hydroxide having a higher water concentration than boehmite. In certain embodiments, pseudoboehmite can be "Catapal" grade pseudoboehmite. In certain embodiments, the percentage of alumina in the composition can be between about 10 and 30% by weight, alternately between about 15 and 25% by weight, alternately between about 20 and 30% by weight.

[0023] In certain embodiments, the binder material, for example, an alumina material can optionally be peptized with a mono-protic acid, for example, HNO_3 or HCl . The peptized alumina material is believed to provide catalyst particles of enhanced physical strength. The peptized alumina enhance the binding, thereby improving the physical strength of FCC catalyst microspheres.

[0024] In certain embodiments, FCC catalyst includes a matrix can be an alumina containing material, such as a peptized pseudoboehmite, which can act as a binder.

[0025] In certain embodiments, FCC catalyst includes a clay filler material. In certain embodiments, the clay filler material includes a clay mineral. In at least one embodiment, the clay filler material includes kaolin. The FCC catalyst includes a clay filler material with an absence of pillared clay. The clay filler materials appropriate for use in the FCC catalyst of the invention do not act as a promoter. In certain embodiments, the percentage of clay filler material includes between about 30 and 50% by weight, alternately between about 30 and 40% by weight, alternately between about 35 and 45% by weight, alternately between about 40 and 50% by weight.

[0026] In other embodiments, FCC catalyst includes ingredients that are typically utilized for such compositions, such as alumina, silica, silica-alumina, titania, zirconia, clays, binders, and the like. The FCC catalyst is prepared and used in an absence of colloidal silica. In alternate embodiments, the catalyst composition can include other metal compounds, such as metal oxides, silicon oxide or aluminum oxide, metal hydroxides, and the like. In certain embodiments, FCC catalyst can be advantageously combined to form a shaped particle, such as a microsphere. In certain embodiments, the catalyst composition can be shaped into a shaped particle, such as a microsphere, and used in an FCC process, resulting in an increased propylene yield.

[0027] In one embodiment, FCC catalyst for enhanced production of light olefins from heavy hydrocarbon feedstock is provided. FCC catalyst includes between about 10-30% by weight of an ultra-stable Y-type zeolite; between about 10-30% by weight of pentasil zeolite; between about 10-30% by weight of a binder material; and between about 30-50% by weight of a clay filler material. In the catalyst of the present formulation, the two zeolites can exist within the same catalyst particle and can share the same matrix.

[0028] In another embodiment, FCC catalyst for enhanced production of light olefins from heavy hydrocarbon feedstock is provided. The catalyst includes between about 10-20% by weight of an ultra-stable Y-type zeolite; between about 10-20% by weight of pentasil zeolite; between about 20-30% by weight of a binder material; and between about 30-40% by weight of a clay filler material. In the catalyst of the present formulation, the two zeolites can exist within the same catalyst particle and can share the same matrix.

[0029] In another embodiment, FCC catalyst for enhanced production of light olefins from heavy hydrocarbon feedstock is provided. The catalyst includes between about 10-20% by weight of an ultra-stable Y-type zeolite; between about 10-20% by weight of pentasil zeolite; between about 20-30% by weight of a binder material; and between about 30-40% by weight of a clay filler material. In the catalyst of the present formulation, the two zeolites can exist within the same catalyst particle and can share the same matrix.

[0030] In another embodiment, FCC catalyst enhanced production of light olefins from heavy hydrocarbon feedstock is provided. The catalyst includes between about 10-20% by weight of an ultra-stable Y-type zeolite; between about 10-20% by weight of sub-micron ZSM-5; between about 20-30% by weight of a binder material; and between about 30-40% by weight of a clay filler material. In the catalyst of the present formulation, the two zeolites can exist within the same catalyst particle and can share the same matrix.

[0031] In another embodiment, FCC catalyst for enhanced production of light olefins from heavy hydrocarbon feedstock is provided. The catalyst includes between about 10-20% by weight of an ultra-stable Y-type zeolite; between about 10-20% by weight of phosphorous modified sub-micron ZSM-5; between about 20-30% by weight of a binder material; and between about 30-40% by weight of a clay filler material. In the catalyst of the present formulation, the two zeolites can exist within the same catalyst particle and can share the same matrix.

[0032] In another embodiment, FCC catalyst for enhanced production of light olefins from heavy hydrocarbon feedstock is provided. The catalyst includes between about 10-20% by weight of an ultra-stable Y-type zeolite; between about 10-20% by weight of phosphorous modified sub-micron ZSM-5; between about 20-30% by weight of an pseudoboehmite alumina material; and between about 30-40% by weight of a clay filler material. In the catalyst of the present formulation, the two zeolites can exist within the same catalyst particle and can share the same matrix.

[0033] In another embodiment, FCC catalyst for enhanced production of light olefins from heavy hydrocarbon feedstock is provided. The catalyst includes between about 10-20% by weight of an ultra-stable Y-type zeolite; between about 10-20% by weight of phosphorous modified sub-micron ZSM-5; between about 20-30% by weight of a peptized pseudoboehmite alumina material; and between about 30-40% by weight of a clay filler

material. In the catalyst of the present formulation, the two zeolites can exist within the same catalyst particle and can share the same matrix.

[0034] In another embodiment, FCC catalyst for enhanced production of light olefins from heavy hydrocarbon feedstock is provided. The catalyst includes between about 10-20% by weight of an ultra-stable Y-type zeolite; between about 10-20% by weight of phosphorous modified sub-micron ZSM-5; between about 20-30% by weight of a peptized pseudoboehmite alumina material; and between about 30-40% by weight of kaolin. In the catalyst of the present formulation, the two zeolites can exist within the same catalyst particle and can share the same matrix.

[0035] In another embodiment, FCC catalyst for enhanced production of light olefins from heavy hydrocarbon feedstock is provided. The catalyst includes between about 10-20% by weight of an ultra-stable Y-type zeolite; between about 10-20% by weight of phosphorous modified sub-micron ZSM-5; between about 20-30% by weight of a peptized pseudoboehmite alumina material; and between about 30-50% by weight of kaolin. In the catalyst of the present formulation, the two zeolites can exist within the same catalyst particle and can share the same matrix.

[0036] In certain embodiments, the catalyst described herein can advantageously be used in a riser reaction vessel or a downer reaction vessel of an FCC process. The catalyst described herein can be used in a high temperature, high severity FCC process. Use of the catalyst described herein in a high temperature, high severity FCC process advantageously minimizes contact time to prevent saturation of the hydrocarbons, while cracking hydrocarbons. As used herein, high severity indicates a high catalyst to feed ratio. The advantage of the high temperature, high severity FCC process is to maximize conversion to propylene. It is understood that one of skill in the art can adapt the described catalyst particles for various types of reaction vessels.

[0037] In certain embodiments, the FCC catalyst described herein can be used in a high severity downer type FCC apparatus.

[0038] Examples

[0039] An FCC process involves a large number of variables and competing reactions. The large number of variables impacts the ability to predict the results based on a change in any one variable and means that a variable of the process cannot be looked at in a vacuum. In addition, the reactions of the catalytic cracking of mixed hydrocarbons cannot be considered

in a vacuum because there are competing reactions not only between the many various components, but also between paths such as cracking and saturation reactions. In short, the degree of unknown makes accurate simulation of such processes impossible and the effect of proposed changes to the process unpredictable. Attempts to accurately simulate the reaction product mixture of an FCC process using the FCC catalyst described herein could not account for the numerous variables in components, and competing reactions. The following examples were necessary to understand the impact of using the FCC catalyst described herein.

[0040] In an FCC process, cracking and saturation are competing reaction paths. The extent of diffusion and the hydrogen transfer reaction depends to some degree on the contact time of the various reaction components and whether the reaction tends toward saturated or unsaturated reaction products.

[0041] Catalyst Preparation Example: ZSM-5 zeolite was impregnated with a solution of mono-ammonium phosphate, as described by Corma et al. (Journal of Catalysis, 237 (2006) 267-277). The ZSM-5 powder was slurried in a solution of mono-ammonium phosphate, such that the percentage of solids in the slurry was approximately 10% by weight, and the amount of phosphorous in the solution was approximately 10% by weight, as based on the dry weight of the ZSM-5 zeolite. The slurry was heated with stirring at about 85°C and evaporated to dryness. The resulting material was further dried at about 100°C for two hours, and then calcined at about 500°C for one hour to produce a phosphorous modified ZSM-5 zeolite, referred to as P-ZSM-5.

[0042] An FCC catalyst was prepared by blending 60 g (dry basis) P-ZSM-5 and 30 g (dry basis) ultra-stable Y-type zeolite (USY) with 410 g distilled water for two minutes to produce a zeolite slurry. To this zeolite slurry, 150 g (dry basis) kaolin clay powder was added, and the resulting slurry blended for five minutes.

[0043] Separately, a slurry of Catapal alumina was prepared by mixing 60 g (dry basis) Catapal alumina with 320 g distilled water. The slurry was peptized by adding 7.6 g concentrated nitric acid (70% by weight) and stirring for thirty minutes. The resulting peptized Catapal slurry was then added to the zeolite-kaolin slurry and blended for ten minutes to produce a viscous slurry wherein the individual catalyst particles remained suspended in the solution.

[0044] The resulting viscous slurry was dried at about 125°C, then granulated and sieved. The granules that passed through an 18 mesh screen (1000 microns) and were retained on a

20 mesh screen (841 microns) were calcined, steam deactivated, and tested in a microactivity (MAT) test. The catalyst product produced approximately 20% by weight propylene. The sieved catalyst was then steamed at 810°C for approximately 6 hours in 100% steam. The resulting steamed catalyst was then tested in MAT according to ASTM method.

[0045] Example 1

Three samples were prepared according to the above procedure using different ZSM-5 crystal sizes, large crystal (LC), small crystal (SC), and the sub-micron crystal (SMC) of the invention. These catalysts were then tested in a fixed-bed microactivity testing unit using hydrotreated vacuum gas oil (VGO) at 575°C and carbon-to-oxygen (C/O) ratios of 2:5. Table 1 lists the composition of each catalyst. Table 2 lists the product yields obtained for these catalysts determined at a constant conversion of 75%. The results illustrate that the catalyst containing SMC type ZSM-5 yields the greatest amount of C2-C4 olefins, particularly propylene and ethylene. That the catalyst of the invention should provide a result better than previous catalysts was surprising, given the large number of factors and competing reactions in this system. Attempts to accurately simulate the reaction product mixture of the FCC process using the FCC catalyst described herein could not account for the numerous variables in components, and competing reactions. The results in Table 2 show that the invention advantageously optimizes propylene production, although butenes decrease.

Table 1.

Catalyst Code	ZSM-5		USY	Alumina	Kaolin
	Type	Weight %	Weight %	Weight %	Weight %
Cat. 1	LC	30	10	20	40
Cat. 2	SC	30	10	20	40
Cat. 3	SMC	30	10	20	40

Table 2.

	Cat. 1	Cat. 2	Cat. 3
Compound	Yields, weight %		
Ethylenes (C ₂)	2.5	2.9	3.1

Propylenes (C ₃)	12.0	14.0	14.8
Butenes (C ₄)	11.5	13.1	12.7
C ₂ -C ₄ Olefins	26.1	30.0	30.5
H ₂	0.32	0.27	0.20
C ₁	1.4	1.4	1.2
C ₂	1.2	1.1	1.2
C ₃	1.3	1.2	1.2
iC ₄	2.5	2.6	3.1
nC ₄	0.59	0.64	0.61
Groups			
Dry Gas	5.4	5.7	5.6
LPG	27.9	31.5	32.4
Gasoline	38.8	34.9	33.0
LCO+HCO	24.8	27.9	25.2
Coke	2.5	2.4	2.5

[0046] Example 2.

[0047] Three samples were prepared according to the above procedure using the SMC ZSM-5 zeolite. The SMC ZSM-5 zeolite was treated with different levels of phosphorous (P). The resulting catalysts were then tested in a fixed-bed MAT unit using hydrotreated VGO at 575°C and C/O ratios of 2:5. Table 3 lists the composition of these catalysts. Table 4 lists the product yields obtained for these catalysts, as determined at a constant conversion of 75%. Attempts to accurately simulate the reaction product mixture of the FCC process using the FCC catalyst described herein could not account for the numerous variables in components, and competing reactions. The results generally demonstrate that maximum propylene and ethylene yields are achieved with low level phosphorous treatment, which advantageously also produces decreased amounts of coke.

Table 3

Catalyst Code	SMC ZSM-5		USY	Alumina	Kaolin
	P level	Weight %	Weight %	Weight %	Weight %
Cat. 4	0	30	10	20	40
Cat. 5	Low	30	10	20	40
Cat. 6	High	30	10	20	40

Table 4

	Cat. 4	Cat. 5	Cat. 6
Compound	Yields, weight %		
Ethylenes (C ₂)	3	4.1	3.5
Propylenes (C ₃)	14.8	15.8	15.2
Butenes (C ₄)	12.7	12.8	12.7
C ₂ -C ₄ Olefins	30.5	32.7	31.4
H ₂	0.19	0.16	0.20
C ₁	1.3	1.2	1.5
C ₂	1.2	1.1	1.4
C ₃	1.3	1.2	1.2
iC ₄	3.0	3.2	2.1
nC ₄	0.60	0.46	1.1
Groups			
Dry Gas	5.6	6.6	6.6
LPG	32.4	33.5	32.3
Gasoline	33.5	31.6	34.6
LCO+HCO	4.3	4.4	3.3
Coke	2.7	1.4	1.7

[0048] Example 3.

[0049] Two samples were prepared according to the above procedure to determine the effect of the ultra-stable Y-type (USY) zeolite concentration. The samples included 10% by weight and 20% by weight USY zeolite along with SMC ZSM-5. The resulting catalysts were then tested in a fixed-bed MAT unit using hyrotreated VGO at 575°C and C/O ratios of 2:5. Table 5 provides the composition of these catalysts. Table 6 lists the product yields obtained for these catalysts, as determined at a constant conversion of 75%. Attempts to accurately simulate the reaction product mixture of the FCC process using the FCC catalyst described herein could not account for the numerous variables in components, and competing reactions. The results illustrate that lower USY zeolite concentration provides increased propylene and ethylene yields.

Table 5.

Catalyst Code	SMC ZSM-5	USY	Alumina	Kaolin
	Weight %	Weight %	Weight %	Weight %
Cat. 7	30	10	20	40
Cat. 8	30	20	20	30

Table 6

	Cat. 7	Cat. 8
Compound	Yields, weight %	
Ethylenes (C ₂)	3.11	2.87
Propylenes (C ₃)	14.9	11.4
Butenes (C ₄)	12.9	11.38
C ₂ -C ₄ Olefins	30.91	25.65
H ₂	0.19	0.12

C ₁	1.26	1.38
C ₂	1.19	1.42
C ₃	1.32	0.95
iC ₄	3.02	1.9
nC ₄	0.6	0.4
Groups		
Dry Gas	5.76	5.8
LPG	32.8	26.1
Gasoline	34.7	42.2
LCO+HCO	26	25
Coke	13.6	11.6

[0050] Example 4.

[0051] In this example, the catalyst was prepared using an “alumina sol” process, which is a high solids, high viscosity process wherein the pseudoboehmite alumina acts an active binder for the catalyst. This is a route used to produce FCC catalysts. The catalyst of the present example was tested in a circulating catalyst pilot plant (CCPP) with a downer reactor at a temperature of 575°C. Hydrotreated VGO was supplied as the feedstock. The amount of catalyst used was about 5 kg, the feed oil rate was about 500 g/h, the reactor outlet temperature was maintained at about 575°C, the reaction pressure was 1 kg/cm²G, the regeneration temperature was maintained at about 720°C, and a 10% by weight dispersion steam was used. Table 7 lists the conversion and product yields obtained with the CCPP reactor. Attempts to accurately simulate the reaction product mixture of the FCC process using the FCC catalyst described herein could not account for the numerous variables in components, and competing reactions. These results show that the catalyst of present invention gives a propylene yield of up to about 21% by weight, at a C/O ratio of 41.0, and a gasoline yield of up to about 34% by weight.

Table 7. Conversion and Product Yields (CCPP, 575°C).

Catalyst ID	MB3-13 SD	MB3-13 SD	MB3-13 SD
C/O ratio	16.5	24.8	41.2
Conversion %	78.4	84.2	86.7
Compounds	Yields, weight %		
Ethylenes (C ₂)	2.6	2.6	3.1
Propylenes (C ₃)	16.0	17.9	20.8
Butenes (C ₄)	15.4	17.1	17.9
C ₂ -C ₄ Olefins	34.0	37.6	41.8
H ₂	0.1	0.1	0.1
C ₁	1.4	1.0	1.0
C ₂	1.1	0.7	0.6
C ₃	0.90	1.03	1.33
iC ₄	1.5	2.1	3.1
nC ₄	0.4	0.6	0.8
Groups			
Dry Gas	5.2	4.4	4.9
LPG	34.1	38.8	43.9
Gasoline	35.7	37.5	34.4
Light Cycle Oil (LCO)	11.3	10.2	8.9
Heavy Cycle Oil (HCO)	10.3	5.6	4.4
Coke	0.9	1.2	1.6
Total	98	98	98

[0052] Example 5.

[0053] VGO cracking was performed in the CCPP reactor described in Example 4 at temperatures ranging from 550°C to 600°C with a catalyst. Data obtained for cracking at temperatures of 550°C, 575°C and 600°C is listed in Table 8. Attempts to accurately simulate the reaction product mixture of the FCC process using the FCC catalyst described herein could not account for the numerous variables in components, and competing reactions. The data demonstrates that the catalyst can be used to crack VGO at temperatures that are similar to those that are presently used in conventional FCC processes.

Table 8.

Temperature, °C	550°C	575°C	600°C
C/O ratio	38.7	41.2	41.7
Conversion %	86.4	86.7	87.3
Compounds	Yields, weight %		
Ethylenes (C ₂)	2.6	3.1	3.7
Propylenes (C ₃)	19.6	20.8	21.6
Butenes (C ₄)	17.5	18.0	22.2
C ₂ -C ₄ Olefins	39.7	41.8	43.8
H ₂	0.1	0.1	0.1
C ₁	0.7	1.0	1.5
C ₂	0.5	0.6	0.9
C ₃	1.34	1.33	1.34
iC ₄	3.9	3.1	2.6
nC ₄	0.9	0.8	0.7
Groups			
Dry Gas	3.9	4.9	6.2

LPG	43.1	43.9	44.7
Gasoline	35.6	34.4	33.1
Light Cycle Oil (LCO)	9.3	8.9	8.4
Heavy Cycle Oil (HCO)	4.4	4.4	4.2
Coke	1.7	1.6	1.7
Total	97.9	98.1	98.4

[0054] Example 6.

[0055] The performance of one embodiment of the catalyst of the present invention was compared with a mixture that includes a commercial FCC catalyst and an additive. Hydrotreated VGO was cracked at 600°C in CCPP, at the conditions listed in Example 4. The results are provided in Table 9 and show that the catalyst provides greater yield of C₄ olefins, with comparable yields of C₃ olefins. Gasoline production with the catalyst described herein is greater than that of the commercial FCC catalyst and additive mixture, while coke production is approximately the same. Attempts to accurately simulate the reaction product mixture of the FCC process using the FCC catalyst described herein could not account for the numerous variables in components, and competing reactions.

Table 9.

Cat. ID	MB3-13 SD	Mix 75
C/O ratio	41.7	47.0
Conversion %	87.3	87.1
Compounds	Yields, weight %	
Ethylenes (C ₂)	3.7	6.6
Propylenes (C ₃)	21.6	22.1
Butenes (C ₄)	19.3	16.5
C ₂ -C ₄ Olefins		

H ₂	0.1	0.1
C ₁	1.5	2.9
C ₂	0.9	1.9
C ₃	1.3	1.9
iC ₄	2.6	2.4
nC ₄	0.7	0.8
Groups		
Dry Gas	6.2	11.4
LPG	45.6	43.5
Gasoline	33.1	29.9
Light Cycle Oil (LCO)	8.4	8.0
Heavy Cycle Oil (HCO)	4.2	4.9
Coke	1.7	1.7

[0056] Example 7.

[0057] Gasoline composition of selected samples from pilot plant experiments was determined by GC-PIONA analysis. Table 10 lists this composition. Attempts to accurately simulate the reaction product mixture of the FCC process using the FCC catalyst described herein could not account for the numerous variables in components, and competing reactions.

Table 10.

Component	550°C	575°C
n paraffin	3.8	5.3
iso paraffin	13.5	12.3
Olefins	19.3	12.3

Naphthbenes	5.7	4.8
Aromatics	57.7	61.1
Benzene	1.9	2.1
Toluene	8.1	9.1
p-xylene	3.0	3.3
m-xylene	5.9	6.5
o-Xylene	3.0	3.3
GC-RON	88.6	89.2

[0058] The methods and compositions provided herein solve several problems that are frequently encountered

[0059] Although the present invention has been described in detail, it should be understood that various changes, substitutions, and alterations can be made hereupon without departing from the principle and scope of the invention. Accordingly, the scope of the present invention should be determined by the following claims and their appropriate legal equivalents.

[0060] The singular forms "a", "an" and "the" include plural referents, unless the context clearly dictates otherwise.

[0061] Optional or optionally means that the subsequently described event or circumstances may or may not occur. The description includes instances where the event or circumstance occurs and instances where it does not occur.

[0062] Ranges may be expressed herein as from about one particular value, and/or to about another particular value. When such a range is expressed, it is to be understood that another embodiment is from the one particular value and/or to the other particular value, along with all combinations within said range. Similarly, when a range is expressed as "less than" a particular value, this indicates a value that is less than or equal to the particular value unless indicated otherwise by the context of the specification.

[0063] Throughout this application, where patents or publications are referenced, the disclosures of these references in their entirety are intended to be incorporated by reference

into this application, in order to more fully describe the state of the art to which the invention pertains, except when these references contradict the statements made herein.

[0064] As used herein and in the appended claims, the words "comprise," "has," and "include" and all grammatical variations thereof are each intended to have an open, non-limiting meaning that does not exclude additional elements or steps.

[0065] As used herein, terms such as "first" and "second" are arbitrarily assigned and are merely intended to differentiate between two or more components of an apparatus. It is to be understood that the words "first" and "second" serve no other purpose and are not part of the name or description of the component, nor do they necessarily define a relative location or position of the component. Furthermore, it is to be understood that the mere use of the term "first" and "second" does not require that there be any "third" component, although that possibility is contemplated under the scope of the present invention.

CLAIMS

1. An FCC catalyst for increased production of propylene and gasoline from heavy hydrocarbon feedstock, the catalyst comprising:

20% by weight of an ultra-stable Y-type zeolite;

30% by weight of a phosphorous modified sub-micron ZSM-5;

20% by weight of a pseudoboehmite alumina; and

30% by weight kaolin,

wherein the phosphorous modified sub-micron ZSM-5 has a silica to alumina molar ratio in the range of between 1:2 and 1:4.

2. The catalyst of claim 1, wherein the phosphorous modified sub-micron ZSM-5 has a crystal size of less than 3 micron.

3. The catalyst of any of the preceding claims, wherein the phosphorous modified sub-micron ZSM-5 includes between 5 and 10% by weight phosphorous, present as P_2O_5 .

4. The catalyst of any of the preceding claims, wherein the pseudoboehmite alumina is peptized.

5. An FCC catalyst for enhanced production of light olefins from heavy hydrocarbon feedstock, the catalyst comprising:

10% by weight of an ultra-stable Y-type zeolite;

30% by weight of a pentasil zeolite;

20% by weight of a binder material; and

40% by weight clay filler material,

wherein the pentasil zeolite has a silica to alumina molar ratio in the range of between 1:2 and 1:4.

6. The catalyst of claim 5, wherein the pentasil zeolite is phosphorous modified sub-micron ZSM-5.

7. The catalyst of any of claim 5, wherein the binder material is a pseudoboehmite alumina.

8. The catalyst of any of claim 5, wherein the clay filler material is kaolin.

9. A process for the fluid catalytic cracking of a heavy hydrocarbon feedstock, the process comprising the steps of:

supplying a heavy hydrocarbon feedstock to the reaction zone of an FCC reactor and contacting the heavy hydrocarbon feedstock with a catalyst, the catalyst comprising between 10 and 20% by weight of a phosphorous modified sub-micron ZSM-5, between 10 and 20% by weight of an ultra-stable Y-type zeolite, between 20 and 30% by weight of a pseudoboehmite alumina, and between 20 and 40% by weight kaolin; and

maintaining the reaction zone such that the outlet temperature of the reaction zone is maintained at a temperature of 550°C,

wherein the catalyst and the heavy hydrocarbon feedstock are contacted for a time sufficient to crack the heavy hydrocarbon feedstock to product an effluent that comprises gasoline and propylene, and

wherein the phosphorous modified sub-micron ZSM-5 has a silica to alumina molar ratio in the range of between 1:2 and 1:4.

10. The process of claim 9, wherein the heavy hydrocarbon feedstock comprises a vacuum gas oil.

11. The process of any of claims 9 or 10, further comprising the step of regenerating the catalyst at a temperature of at least 700°C.