

A catalyst and a method for cracking hydrocarbons

TECHNICAL FIELD

The present invention relates to a catalyst and a method for
5 cracking hydrocarbons. More particularly, the present invention
relates to a catalyst and a method for cracking hydrocarbons used to
increase the concentration of propylene in FCC liquefied petroleum
gas (LPG).

TECHNICAL BACKGROUND

Propylene is an important organic chemical raw material. With
the rapid increase of the demand for the derivatives such as
polypropylene, the requirement for propylene in the whole world is
increased rapidly year by year. Fluid catalytic cracking is one of the
15 most important technologies to produce light olefins and propylene. As
for most of the FCC apparatus, using the catalyst or the addition agent
containing zeolite with MFI structure is an effective technology in
order to increase light olefins and propylene.

USP3,758,403 disclosed earlier that the method by adding ZSM-5
20 zeolite in the FCC catalyst might increase the octane number of
gasoline and the yield of C₃~C₄ olefins. For instance, when adding 1.5,
2.5, 5 and 10% ZSM-5 zeolite to the conventional catalyst with 10%
REY molecular sieve, the octane number of gasoline is increased and
the yield of low-carbon olefin is increased. The same result could be
25 obtained by using the addition agent with ZSM-5 zeolite.

USP5,318,696 disclosed a hydrocarbon conversion technology
based on a catalyst which is consisted of a macroporous zeolite and a
zeolite with MFI structure and a Si/Al ratio of lower than 30. This
technology is used to produce gasoline with high octane number by
30 employing improved FCC process and increase low-carbon olefins,
especially propylene.

USP5,997,728 disclosed a method in which a shape-selective

cracking addition agent is used in large amount in the FCC process of heavy feedstock. The addition agent comprises the amorphous matrix by adding 12~40% ZSM-5 zeolite, and its inventory in the system is at least 10%, which makes the content of ZSM-5 zeolite in the catalyst higher than 3%. This method increases low-carbon olefins in a large scale, at the same time it doesn't increase the yield of aromatic extraly and lose the yield of gasoline.

The cracking activity and hydrothermal stability of ZSM-5 zeolite is increased and the use level of zeolite can be reduced after the modification of ZSM-5 zeolite by phosphorous compounds.

CN1049406C disclosed a zeolite with MFI structure which containing P and rare earth. The anhydrous chemical expression is $a\text{RE}_2\text{O}_3 \cdot b\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot c\text{P}_2\text{O}_5 \cdot d\text{SiO}_2$, in which $a=0.01\sim0.25$, $b=0.005\sim0.02$, $c=0.2\sim1.0$ and $d=35\sim120$. This zeolite displays excellent hydrothermal stability and good selectivity of low-carbon olefins when used in the conversion of hydrocarbons at high temperature.

CN1034223C disclosed a cracking catalyst used to produce low-carbon olefins, which is consisted of 0~70% clay (based on weight of catalyst), 5~99% inorganic oxide and 1~50% zeolite. The zeolite is the mixture of 0~25wt% REY or high silica Y zeolite and 75~100wt% five membered ring high silica zeolite containing P and rare earth. The catalyst has higher hydrothermal activity and stability, conversion and yield of $\text{C}_2=\sim\text{C}_4=$ than the catalyst using conventional ZSM-5 zeolite as active component.

USP5,110,776 disclosed the preparation of ZSM-5 zeolite catalyst modified with P, in which the modification procedure with P is proceeded by dispersing the zeolite into a solution of P compounds at a pH value of 2~6, mixing with matrix and spray-drying. The obtained catalyst increases the octane number of gasoline, and at the same time it doesn't increase the yield of dry gas and coke.

USP6,566,293 disclosed a cracking catalyst comprising P modified ZSM-5 zeolite. The preparation of P modified ZSM-5 zeolite is

proceeded by dispersing the zeolite into a solution of P compounds at a pH value of higher than 4.5, in which the loading content of P (calculated by P_2O_5) is at least 10wt%, then mixing with matrix and other zeolite components and spray-drying. The obtained catalyst has
5 high yield of low-carbon olefins.

USP5,171,921 disclosed a ZSM-5 zeolite modified by P. The Si/Al ratio of the zeolite is 20~60. After the immersion with P compounds and steam-aging treatment at 500~700°C, the zeolite displays higher activity than the zeolite without P modification when used in the
10 conversion of $C_3\sim C_{20}$ hydrocarbons to $C_2\sim C_5$ olefins.

USP6,080,303 disclosed a method used to increase the catalytic activity of microporous and mesoporous zeolites, in which microporous and mesoporous zeolites are treated with P compounds firstly and then combined with $AlPO_4$ gel. This method may improve
15 the activity and hydrothermal stability of microporous and mesoporous zeolites.

USP5,472,594 disclosed a hydrocarbon conversion technology based on a catalyst which comprises a microporous zeolite and a P modified mesoporous zeolite with MFI structure. This technology is
20 used to produce gasoline with high octane number by employing improved FCC process and increase low-carbon olefins, especially C_4/C_5 .

Besides the P modification of ZSM-5 zeolite, the selectivity of the catalyst and addition agent for low-carbon olefins also could be
25 improved by the introduction of P compounds to matrix.

USP2002/0003103A1 disclosed a FCC technology employed to increase the yield of propylene, in which at least part of the gasoline products are piped into the second riser reactor and cracked again. Besides microporous zeolite such as USY, the catalyst composition
30 used comprises mesoporous zeolite such as ZSM-5 and inorganic binder possessing cracking activity. The inorganic binder component contains P and the P/Al ratio is 0.1~10. This technology may increase

low-carbon olefins in a large scale, especially the yield of propylene.

USP2002/0049133A1 disclosed a catalyst with high zeolite content and high attrition strength. The catalyst comprises 30~85wt% ZSM-5 zeolite, 6~24wt% P (calculated by P_2O_5), <10wt% Al_2O_3 and the remainder clay, in which P exists in matrix. When used in FCC process, the catalyst can increase light olefins, especially the yield of propylene.

The method of modifying zeolite with metal and its application were reported in following patents. For instance, USP5,236,880 disclosed a catalyst containing the zeolites with MFI or MEL structures, in which the zeolite is modified by the metal of Group VIII, preferred by Ni. After the introduction of Ni, the zeolite is treated at a controlled temperature under thermal or hydrothermal conditions, which leads to the enrichment of the metal of Group VIII and Al on the surface. When used in the conversion of hydrocarbons, the catalyst may increase the octane number of gasoline and the yield of $C_3\sim C_4$ olefins.

CN1057408A disclosed a cracking catalyst containing high Si zeolite and high cracking activity, in which the high Si zeolite is ZSM-5 zeolite, β zeolite or MOR zeolite containing 0.01~3.0wt% P, 0.01~1.0wt% Fe or 0.01~10wt% Al. The high Si zeolite is obtained by heating H- or K-ZSM-5 zeolite, β zeolite or MOR zeolite with a Si/Al ratio of higher than 15 to 350~820°C and passing it into an aqueous solution of Al halide, Fe halide or ammonium phosphate at a volume hourly space velocity of 0.1~10h⁻¹.

CN1465527A disclosed a MFI zeolite with P and transition metal. The anhydrous chemical expression of the zeolite, calculated by mass of oxide, is (0~0.3) $Na_2O \cdot$ (0.5~5) $Al_2O_3 \cdot$ (1.3~10) $P_2O_5 \cdot$ (0.7~15) $M_2O_3 \cdot$ (70~97) SiO_2 , in which M is selected from one of the transition metals Fe, Co and Ni. When used in the FCC procedure of petroleum hydrocarbon, the zeolite may increase the yield and selectivity for $C_2\sim C_4$ olefins and result in higher yield of LPG.

At present for most of the FCC apparatus, increasing the concentration of propylene in LPG is an important way to increase the economic benefits for FCC apparatus at the same yield of LPG. Although the zeolite materials and catalysts disclosed in the prior art could effectively increase the yield of low-carbon olefins and the octane number of FCC gasoline products when used in FCC process, during the FCC reaction they give out relative low selectivity for propylene, so the scope for increasing propylene concentration in LPG is limited.

DISCLOSURE OF THE INVENTION

The object of the invention is to provide a new catalyst on the basis of the prior art and a method for cracking hydrocarbons by using this catalyst.

The inventor have found that the catalyst, prepared by using the modified MFI zeolite containing P and transition metal as disclosed in CN1465527A as active component, and introducing a proper content of transition metal additive and P additive further, could increase not only the yield of LPG in FCC effectively and the octane number of FCC gasoline, but also increase the concentration of propylene in LPG of FCC dramatically when used in the method for cracking hydrocarbons.

Therefore the catalyst supplied by this invention is characterized by that the catalyst comprises, calculated by dry basis, 10~65wt% ZSM-5 zeolite, 0~60wt% clay, 15~60wt% inorganic oxide binder, 0.5~15wt% one or more metal additives selected from the metals of Group VIIIIB and 2~25wt% P additive, in which the metal additive and the P additive are both calculated by oxide.

The catalyst supplied by this invention is preferably consisted of, calculated by dry basis, 20~50wt% ZSM-5 zeolite, 10~45wt% clay, 25~50wt% inorganic oxide binder, 1.0~10wt% one or more metal additives selected from the metals of Group VIIIIB and 5~15wt% P

additive. In which the ZSM-5 zeolite is preferably a ZSM-5 zeolite modified by P and one of the metals selected from Fe, Co and Ni. The anhydrous chemical expression, calculated by oxide, is $(0\sim0.3) \text{Na}_2\text{O} \cdot (0.5\sim5) \text{Al}_2\text{O}_3 \cdot (1.3\sim10) \text{P}_2\text{O}_5 \cdot (0.7\sim15) \text{M}_x\text{O}_y \cdot (70\sim97) \text{SiO}_2$, in which x is the atom number of M and y is a number needed to satisfy the oxidation state of M. In preferred condition, the modified ZSM-5 zeolite is modified by P and Fe, and the anhydrous chemical expression, calculated by oxide, is $(0\sim0.2) \text{Na}_2\text{O} \cdot (0.9\sim3.5) \text{Al}_2\text{O}_3 \cdot (1.5\sim7) \text{P}_2\text{O}_5 \cdot (0.9\sim10) \text{M}_x\text{O}_y \cdot (82\sim92) \text{SiO}_2$.

In the catalyst supplied by this invention, the contents of metal additive of Group VIIIB and P additive do not include the contents of transition metal and P in the modified ZSM-5 zeolite.

In the catalyst supplied by this invention, under preferred condition, the metal of Group VIIIB is selected from one or more of Fe, Co and Ni, more preferably Fe. When using Fe as additive, the XRD patterns of the catalyst comprises at least the characteristic diffraction peaks of FePO species at $2\theta=16.35\pm0.5^\circ$, $2\theta=26.12\pm0.5^\circ$ and $2\theta=30.94\pm0.5^\circ$.

In the catalyst supplied by this invention, the clay is well known for the technicians in the art and there is no special limitation to it in this invention. It could be selected from one or mixture of more than one of kaolin, metakaolin, sepiolite, attapulgite clay, montmorillonite, rectorite, diatomite, halloysite, steatite, bentonite, hydrotalcites, preferably from one or mixture of more than one of kaolin, metakaolin, diatomite, sepiolite, attapulgite clay, montmorillonite and rectorite.

The inorganic oxide binder is selected from one or more of the inorganic oxides used as matrix and binder component of catalyst, which are well known for the technicians in the art and there is no special limitation to it in this invention. It is selected from one or mixture of more than one of pseudoboehmite, alumina sol, silica-alumina sol, water glass and phosphorus-alumina sol, preferably

from one or mixture of more than one of pseudoboehmite, alumina sol and phosphorus-alumina sol. When the addition agent has phosphorus-alumina sol, the content of P in the phosphorus-alumina sol, calculated by P_2O_5 , is added into the content of P additive.

5 The catalyst supplied by this invention could be prepared from zeolite, clay and inorganic oxide binder through any methods disclosed in the existing preparation technologies of cracking catalyst such as spray-drying process, and there is no special limitation in this invention.

10 The transition metal additives of Group VIIIB exist in the form of their oxide, phosphate, phosphite, basic phosphate, acid phosphate.

One or more of the inorganic compounds and organic compounds of the transition metal could be easy to dissolve in water, or hard to dissolve or insoluble in water. The examples of the transition metal
15 compounds include their oxide, hydroxide, chloride, nitrate, sulphate, phosphate and their organic compounds, etc. The preferred transition metal compounds are selected from one or more of their chloride, nitrate, sulphate and phosphate.

The transition metal additive of Group VIIIB is preferably
20 introduced by adding transition metal compounds to the slurry in any step before spray-drying in the preparation process of the catalyst. It also can be introduced after spray-drying through immersion or chemical adsorption of transition metal compounds and calcination process, including to immerse the catalyst with a aqueous solution of
25 transition metal compounds or to treat it by chemical adsorption method, then to separate the solid and the liquid (if needed), and to dry and calcine. The drying temperature is from room temperature to 400°C, preferred 100~300°C. The calcination temperature is 400~700°C, preferred 450~650 °C. The calcination time is 0.5~100h, preferred
30 0.5~10h.

So the transition metal additive may exist in any possible positions of the catalyst, such as the internal channel of the zeolite, the

surface of the zeolite, the matrix, or exist in the internal channel of the zeolite, the surface of the zeolite and the matrix simultaneously, preferred in the matrix.

In the catalyst supplied by this invention, the P additive exists in the form of phosphorous compounds (such as the oxide of phosphorus, phosphate, phosphite, basic phosphate and acid phosphate). The P additive can be introduced into the catalyst by one of the following methods or the combination of the following methods, but not limited to these methods:

1. Adding phosphorous compounds to the slurry before spray-drying process;

2. Introduced into the catalyst by the inorganic oxide binder. For instance, when the inorganic oxide binder containing phosphorus-alumina sol, after the catalyst is calcined, P is introduced into the catalyst. The phosphorus-alumina sol could also be used as matrix and binder, so this part of P also belongs to the P additive supplied by this invention.

3. Introduced into the catalyst after spray-drying process through immersion or chemical adsorption of phosphorous compounds, solid-liquid separation (if needed), drying and calcination process. The drying temperature is from room temperature to 400°C, preferred 100~300°C. The calcination temperature is 400~700°C, preferred 450~650°C. The calcination time is 0.5~100h, preferred 0.5~10h.

So the P additive may exist in any possible positions of the catalyst, such as the internal channel of the zeolite, the surface of the zeolite, in the matrix, or exist in the internal channel of the zeolite, the surface of the zeolite and the matrix simultaneously.

In the preparation method of the catalyst supplied by this invention, the phosphorous compounds are selected from one or more of the inorganic compounds and organic compounds of phosphorus. The phosphorous compounds could be easy to dissolve in water, or hard to dissolve or insoluble in water. The examples of the

phosphorous compounds include the oxide of phosphorus, phosphoric acid, phosphate, phosphite, hypophosphite and organic compounds of phosphorus. The preferred phosphorous compounds are selected from one or more of H_3PO_4 , $(\text{NH}_4)_3\text{PO}_4$, $(\text{NH}_4)\text{H}_2\text{PO}_4$, $(\text{NH}_4)_2\text{HPO}_4$, AlPO_4 and phosphorus-alumina sol.

A method for cracking hydrocarbons using above catalysts is also supplied in this invention, in which hydrocarbons are contacted with a mixture of catalysts mentioned above under cracking condition, and then the cracked products are collected.

In the cracking method supplied by this invention, the contact of the hydrocarbons and the mixture of catalysts could be proceeded in all kinds of reactors. The reactor could be a riser reactor, a fixed-bed reactor, a fluidized-bed reactor or a moving-bed reactor, preferably the reactor is the riser reactor.

The contact conditions include a contact temperature of $400\sim 650^\circ\text{C}$, preferred $420\sim 600^\circ\text{C}$, and a catalyst-to-oil ratio (the weight ratio of catalyst to hydrocarbon) of $1\sim 25$, preferred $3\sim 20$.

As for a fixed-bed reactor, a fluidized-bed reactor or a moving-bed reactor, the contact condition also includes the weight hourly space velocity of $10\sim 120\text{h}^{-1}$, preferred $15\sim 80\text{h}^{-1}$. But for a riser reactor the contact condition further includes the reaction time of $0.5\sim 15\text{s}$, preferably $0.5\sim 10\text{s}$.

In the cracking method supplied by this invention, the mixture of catalysts containing the catalysts mentioned above are consisted mainly of a main cracking catalyst and the catalyst mentioned above and the content of them is well known for the technicians in the art. In general, in the mixture of catalysts the content of the main cracking catalyst is $70\sim 99\text{wt}\%$, preferred $80\sim 95\text{wt}\%$, and the content of the catalyst supplied by this invention is $1\sim 30\text{wt}\%$, preferably $3\sim 20\text{wt}\%$.

In the catalyst mixture, the type and the composition of the main cracking catalyst is well known for the technicians in this area, which may be all kinds of cracking catalysts, such as all kinds of cracking

catalyst containing zeolite.

In the cracking method supplied by this invention, the hydrocarbons are selected from one or more of all kinds of petroleum cuts, such as crude oil, atmospheric residuum, vacuumed residuum, atmospheric gas oil, vacuumed gas oil, straight run gas oil, propane deasphalted oil, coking gas oil and liquefied products of coal. The hydrocarbons may have heavy metal impurities such as Ni and V, and impurities of S and N, in which the content of S can reach 3.0wt%, the content of N can be up to 2.0wt%, the content of metal impurities such as V and Ni can be as high as 3000ppm.

In the cracking method supplied by this invention, the mixture of catalysts could be used onetime, but in a preferred situation the mixture of catalysts are regenerated and used cyclically. The regeneration of the catalyst mixture is a process that the coke in the catalyst mixture is calcined under oxygen atmosphere which in general is air, as is well known for the technicians in the art. For instance, generally the regeneration temperature is 600~770 °C, preferred 650~730°C. When the contact procedure of the hydrocarbons and the catalyst mixture is proceeded on a fixed-bed reactor, a fluidized-bed reactor or a moving-bed reactor, the regeneration could be finished by piping oxygen-containing atmosphere in situ. When the contact procedure of the hydrocarbons and the catalyst mixture is proceeded on a riser reactor, the regeneration could be finished by using the existing reaction-regeneration system. The existing reaction-regeneration system and the regenerator of FCC are summarized at pages 282~338 in «The processing technique of residuum» (Li Chunnian, Sinopec. Publishing company, 2002).

The catalyst supplied by this invention by adding a proper content of the transition metal additive of Group VIIIB and the P additive, especially the samples using modified ZSM-5 zeolite as active component simultaneously, may increase the selectivity for propylene in FCC process, and consequently increase the concentration of

propylene in LPG of FCC dramatically. For instance, the content of propylene in the products is increased by 0.76~4.05% (Tables 3, 4, 5), the concentration of propylene in LPG is increased to higher than 35.70wt%.

5

Brief description of drawings

Figure 1~Figure 5 are the XRD patterns for the catalysts and the comparative catalysts prepared by the examples and the comparative examples.

10

Examples

The following examples are used to explain the invention, which is not a limitation to the invention.

In the examples and comparative examples, the eight modified ZSM-5 samples A₁~A₈ are prepared according to the method disclosed in CN1465527A. The anhydrous chemical expressions are obtained on the basis of the chemical composition of the zeolite measured by X-ray fluoroscopy.

Sample A₁ : 0.04Na₂O·3.57Al₂O₃·4.0P₂O₅·2.4Fe₂O₃·90.49SiO₂.

20 Sample A₂ : 0.1Na₂O·5.0Al₂O₃·2.0P₂O₅·0.9Fe₂O₃·92SiO₂.

Sample A₃ : 0.1Na₂O·5.3Al₂O₃·1.5P₂O₅·1.1Fe₂O₃·92SiO₂.

Sample A₄ : 0.03Na₂O·2.2Al₂O₃·4.9P₂O₅·2.1Fe₂O₃·90.8SiO₂.

Sample A₅ : 0.1Na₂O·0.94Al₂O₃·5.1P₂O₅·10.1Fe₂O₃·84SiO₂.

Sample A₆ : 0.03Na₂O·5.1Al₂O₃·4.8P₂O₅·3.6Co₂O₃·86.5SiO₂.

25 Sample A₇ : 0.1Na₂O·4.6Al₂O₃·6.9P₂O₅·6.4Ni₂O₃·82SiO₂.

Sample A₈ : 0.1Na₂O·5.2Al₂O₃·4.5P₂O₅·2.0Ni₂O₃·88.2SiO₂.

Pseudoboehmite is an industry product of Shandong Alumina Company with a solid content of 60wt%. Alumina sol is an industry product of Qilu Catalyst Factory with an Al₂O₃ content of 21.5wt%.

30 Water glass is an industry product of Qilu Catalyst Factory with a SiO₂ content of 28.9wt% and a Na₂O content of 8.9wt%. kaolin is a kind of special kaolin for cracking catalyst manufactured by Suzhou

kaolin Company with a solid content of 78wt%. ZRP-5 zeolite is an industry product with conventional MFI structure manufactured by Qilu Catalyst Factory with a P_2O_5 content of 2.5wt% and a crystallinity of 85wt% as well as a Si/Al ratio of 50.

5 In the examples and comparative examples, the characterization method of the XRD patterns for the catalyst samples is:

The XRD patterns were characterized on a D/MAX-III A X-Ray Diffractometer (from Rigaku) at 40kV and 40mA using Cu $K\alpha$ radiation and Ni filter. The sample scans were collected at scan step of
10 0.02° , step time of 1s and diffraction slit of 2mm/2mm/0.2mm.

Examples 1~19 are used to explain the preparation of catalyst employed in the method supplied by this invention.

15 Example 1

The preparation of phosphorus-alumina sol: 1.05 kg pseudoboehmite (dry basis) and 3.35 kg deionized water was mixed together and stirred for 30 min, then 4.9 kg concentrated H_3PO_4 (chemical pure, 85wt% of H_3PO_4) was added into the slurry under
20 stirring. The obtained slurry was heated to $70^\circ C$ and reacted for 45 min at this temperature to form the colorless and transparent phosphorus-alumina sol with a P_2O_5 content of 30.6wt% and an Al_2O_3 content of 10.5wt% as well as $pH=1.7$.

1.75 kg A_1 (dry basis), 1.4 kg kaolin (dry basis), 0.65 kg
25 pseudoboehmite (dry basis), 6.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min, then 1 L aqueous $FeCl_3 \cdot 6H_2O$ solution (having 100 g Fe_2O_3) was added into the slurry under stirring. The pH value of the slurry is 3.0. After stirring for another 45 min, 1.22 kg phosphorus-alumina sol was added into
30 the slurry and stirred evenly. Microspheres with average particle size of $65 \mu m$ were obtained by the spray-drying of the slurry at input temperature of $500^\circ C$ and exhaust (output) temperature of $180^\circ C$. The

catalyst ZJ₁ with 35wt% A₁, 28wt% kaolin, 27.5wt% Al₂O₃, 2.0wt% Fe additive (calculated by Fe₂O₃) and 7.5wt% P additive (calculated by P₂O₅) was obtained after the calcination of the microspheres at 500 °C for 1 h.

5 The XRD pattern of this catalyst is shown in Figure 1 as line a, in which the diffraction peaks at $2\theta=16.35^\circ$, $2\theta=26.12^\circ$ and $2\theta=30.94^\circ$ are the characteristic diffraction peaks of FePO species.

Example 2

10 1.84 kg A₁ (dry basis), 1.33 kg kaolin (dry basis), 0.98 kg pseudoboehmite (dry basis), 7.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min, then 1 L aqueous FeCl₃·6H₂O solution (having 250 g Fe₂O₃) was added into the slurry under stirring. The pH value of the slurry is 3.0. The slurry was
15 stirred for another 45 min. Then microspheres with average particle size of 65 μm were obtained by the spray-drying of the slurry at input temperature of 500°C and exhaust (output) temperature of 180°C. The microspheres with 36.8wt% A₁, 26.6wt% kaolin, 31.6wt% Al₂O₃ and 5.0wt% Fe additive (calculated by Fe₂O₃) were obtained after
20 calcination at 500°C for 1 h.

1 kg microspheres obtained above (dry basis), 10 L deionized water and 100 g (NH₄)₂HPO₄ were mixed together. The obtained slurry was heated to 60°C under stirring and reacted for 20 min at this temperature. The slurry was vacuum-filtrated and dried. The catalyst
25 ZJ₂ with 35wt% A₁, 25.3wt% kaolin, 30wt% Al₂O₃, 4.7wt% Fe additive (calculated by Fe₂O₃) and 5wt% P additive (calculated by P₂O₅) was obtained after calination at 500°C for 2 h.

The XRD pattern of this catalyst is shown in Figure 2 as line e, in which the diffraction peaks at $2\theta=16.37^\circ$, $2\theta=26.22^\circ$ and $2\theta=30.90^\circ$ are
30 the characteristic diffraction peaks of FePO species.

Example 3

1.94 kg A₁ (dry basis), 1.91 kg pseudoboehmite (dry basis), 7.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min, then 1 L aqueous FeCl₃·6H₂O solution (having 550 g Fe₂O₃) was added into the slurry under stirring. The pH value of the slurry is 3.0. The slurry was stirred for another 45 min. Then microspheres with average particle size of 65 μm were obtained by the spray-drying of the slurry at input temperature of 500°C and exhaust temperature of 180°C. The microspheres with 38.8wt% A₁, 50.2wt% Al₂O₃ and 11wt% Fe additive (calculated by Fe₂O₃) were obtained after calcination at 500°C for 1 h.

1 kg microspheres obtained above (dry basis), 10 L deionized water and 210 g (NH₄)₂HPO₄ were mixed together. The obtained slurry was heated to 60°C under stirring and reacted for 20 min. The slurry was vacuum-filtrated and dried. The catalyst ZJ₃ with 35wt% A₁, 45.1wt% Al₂O₃, 9.9wt% Fe additive (calculated by Fe₂O₃) and 10wt% P additive (calculated by P₂O₅) was obtained after calcination at 500°C for 2 h.

The XRD pattern of this catalyst is shown in Figure 2 as line f, in which the diffraction peaks at 2θ=16.25°, 2θ=26.18° and 2θ=30.87° are the characteristic diffraction peaks of FePO species.

Example 4

The preparation method is as same as Example 1, but the difference is that the weight of kaolin is 1.25 kg (dry basis) and FeCl₃·6H₂O solution is replaced by 1 L Co(NO₃)₂·6H₂O solution (having 250 g CoO). The catalyst ZJ₄ was obtained with 35wt% A₁, 25wt% kaolin, 27.5wt% Al₂O₃, 5wt% Co additive (calculated by CoO) and 7.5wt% P additive (calculated by P₂O₅).

Example 5

The preparation method is as same as Example 1, but the difference is that the weight of kaolin is 1.25 kg (dry basis) and

FeCl₃·6H₂O solution is replaced by 1 L Ni(NO₃)₂·6H₂O solution (having 250 g NiO). The catalyst ZJ₅ was obtained with 35wt% A₁, 25wt% kaolin, 27.5wt% Al₂O₃, 5wt% Ni additive (calculated by NiO) and 7.5wt% P additive (calculated by P₂O₅) that doesn't include the P component of the modified MFI zeolite.

Example 6

1 kg catalyst ZJ₁ (dry basis), 10 L deionized water and 157 g (NH₄)₂HPO₄ were heated to 60°C under stirring and reacted for 20 min at this temperature. The slurry was vacuum-filtrated and dried. The catalyst ZJ₆ with 32.38wt% A₁, 25.9wt% kaolin, 25.4wt% Al₂O₃, 1.85wt% Fe additive (calculated by Fe₂O₃) and 14.47wt% P additive (calculated by P₂O₅) was obtained after calcination at 500°C for 2 h.

The XRD pattern of this catalyst is shown in Figure 2 as line g, in which the diffraction peaks at 2θ=16.42°, 2θ=26.08° and 2θ=30.97° are the characteristic diffraction peaks of FePO species.

Example 7

1.75 kg A₁ (dry basis), 1 kg kaolin (dry basis), 3.46 kg water glass and 5 kg deionized water were mixed together and stirred for 120 min, then 1 L aqueous FeCl₃·6H₂O solution (having 750 g Fe₂O₃) was added into the slurry under stirring. The pH value of the slurry is 3.0. After stirring for another 45 min, 1.22 kg phosphorus-alumina sol was added into the slurry and stirred evenly. Microspheres with average particle size of 65 μm were obtained by the spray-drying of the slurry at input temperature of 500°C and exhaust (output) temperature of 180°C. Then the microspheres were calcined at 400°C for 1 h.

1 kg the above calcined microspheres (dry basis), 10 L deionized water and 100 g NH₄Cl were heated to 60°C under stirring, washed for 20 min at this temperature and vacuum-filtrated. The filter cake was washed again according to the above method and dried at 120°C. The catalyst ZJ₇ was obtained with 35wt% A₁, 20wt% kaolin, 2.5wt%

Al_2O_3 , 20wt% SiO_2 , 15wt% Fe additive (calculated by Fe_2O_3) and 7.5wt% P additive (calculated by P_2O_5).

The XRD pattern of this catalyst is shown in Figure 2 as line h, in which the diffraction peaks at $2\theta=16.35^\circ$, $2\theta=26.07^\circ$ and $2\theta=30.88^\circ$ are the characteristic diffraction peaks of FePO species.

Example 8

The catalyst was prepared according to the method of Example 1, but the difference is that the weight of A_1 is 2.25 kg (dry basis) and the weight of kaolin is 0.9 kg (dry basis). The catalyst ZJ₈ was obtained with 45wt% A_1 , 18wt% kaolin, 27.5wt% Al_2O_3 , 2wt% Fe additive (calculated by Fe_2O_3) and 7.5wt% P additive (calculated by P_2O_5).

The XRD pattern of this catalyst is shown in Figure 3 as line i, in which the diffraction peaks at $2\theta=16.38^\circ$, $2\theta=26.20^\circ$ and $2\theta=30.91^\circ$ are the characteristic diffraction peaks of FePO species.

Example 9

1 kg A_1 (dry basis), 1.85 kg kaolin (dry basis), 0.9 kg pseudoboehmite (dry basis), 7.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min, then 1 L aqueous $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ solution (having 400 g Fe_2O_3) was added into the slurry under stirring. The pH value of the slurry is 3.0 adjusted by the dosage of HCl. After stirring for another 30 min, 465 g $(\text{NH}_4)_2\text{HPO}_4$ was added into the slurry and stirred for 30 min. Microspheres with average particle size of 65 μm were obtained by the spray-drying of the slurry at input temperature of 500°C and exhaust temperature of 180°C . The catalyst ZJ₉ with 20wt% A_1 , 37wt% kaolin, 30wt% Al_2O_3 , 8wt% Fe additive (calculated by Fe_2O_3) and 5wt% P additive (calculated by P_2O_5) was obtained after the calcination of the microspheres at 500°C for 1 h.

The XRD pattern of this catalyst is shown in Figure 3 as line j, in which the diffraction peaks at $2\theta=16.35^\circ$, $2\theta=26.07^\circ$ and $2\theta=30.82^\circ$ are

the characteristic diffraction peaks of FePO species.

Example 10

The catalyst was prepared according to the method of Example 9, but the difference is that A₁ is replaced by A₂ with same weight. The catalyst ZJ₁₀ was obtained with 20wt% A₂, 37wt% kaolin, 30wt% Al₂O₃, 8wt% Fe additive (calculated by Fe₂O₃) and 5wt% P additive (calculated by P₂O₅).

The XRD pattern of this catalyst is shown in Figure 3 as line k, in which the diffraction peaks at 2θ=16.32°, 2θ=25.97° and 2θ=30.90° are the characteristic diffraction peaks of FePO species.

Example 11

1.25 kg A₃ (dry basis), 1 kg kaolin (dry basis), 1.65 kg pseudoboehmite (dry basis), 7.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min, then 1 L aqueous FeCl₃·6H₂O solution (having 250 g Fe₂O₃) was added into the slurry under stirring. The pH value of the slurry is 3.0 adjusted by the dosage of HCl. After stirring for another 30 min, 465 g (NH₄)₂HPO₄ was added into the slurry and stirred for 30 min. Microspheres with average particle size of 65 μm were obtained by the spray-drying of the slurry at input temperature of 500 °C and exhaust (output) temperature of 180 °C. The catalyst ZJ₁₁ with 25wt% A₃, 20wt% kaolin, 45wt% Al₂O₃, 5wt% Fe additive (calculated by Fe₂O₃) and 5wt% P additive (calculated by P₂O₅) was obtained after the calcination of the microspheres at 500 °C for 1 h.

The XRD pattern of this catalyst is shown in Figure 3 as line l, in which the diffraction peaks at 2θ=16.31°, 2θ=26.06° and 2θ=30.92° are the characteristic diffraction peaks of FePO species.

Example 12

2 kg A₄ (dry basis), 0.75 kg kaolin (dry basis), 1.15 kg

pseudoboehmite (dry basis), 7.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min, then 1 L aqueous $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ solution (having 250 g Fe_2O_3) was added into the slurry under stirring. The pH value of the slurry is 3.0 adjusted by the dosage of HCl. After stirring for another 30 min, 465 g $(\text{NH}_4)_2\text{HPO}_4$ was added into the slurry and stirred for 30 min. Microspheres with average particle size of 65 μm were obtained by the spray-drying of the slurry at input temperature of 500°C and exhaust temperature of 180°C. The catalyst ZJ₁₂ with 40wt% A₄, 15wt% kaolin, 35wt% Al_2O_3 , 5wt% Fe additive (calculated by Fe_2O_3) and 5wt% P additive (calculated by P_2O_5) was obtained after the calcination of the microspheres at 500°C for 1 h.

The XRD pattern of this catalyst is shown in Figure 4 as line m, in which the diffraction peaks at $2\theta=16.38^\circ$, $2\theta=26.02^\circ$ and $2\theta=30.91^\circ$ are the characteristic diffraction peaks of FePO species.

Example 13

2.89 kg A₅ (dry basis), 1.4 kg pseudoboehmite (dry basis), 7.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min, then 1 L aqueous $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ solution (containing 105.5 g Fe_2O_3) was added into the slurry under stirring. The pH value of the slurry is 3.0. The slurry was stirred for another 45 min. Then microspheres with average particle size of 65 μm were obtained by the spray-drying of the slurry at input temperature of 500°C and exhaust temperature of 180°C. The microspheres with 57.89wt% A₈, 40wt% Al_2O_3 and 2.11wt% Fe additive (calculated by Fe_2O_3) were obtained after calcination at 500°C for 1 h.

1 kg microspheres obtained above (dry basis), 10 L deionized water and 210 g $(\text{NH}_4)_2\text{HPO}_4$ were heated to 60°C under stirring and reacted for 20 min at this temperature. The slurry was vacuum-filtrated and dried. The catalyst ZJ₁₃ with 55wt% A₅, 38wt% Al_2O_3 , 2wt% Fe additive (calculated by Fe_2O_3) and 5wt% P additive

(calculated by P_2O_5) was obtained after calcination at $500^{\circ}C$ for 2 h

The XRD pattern of this catalyst is shown in Figure 4 as line n, in which the diffraction peaks at $2\theta=16.31^{\circ}$, $2\theta=26.09^{\circ}$ and $2\theta=30.80^{\circ}$ are the characteristic diffraction peaks of FePO species.

5

Example 14

1.5 kg A_6 (dry basis), 1.5 kg kaolin (dry basis), 0.9 kg pseudoboehmite (dry basis), 6.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min, then 1 L aqueous $FeCl_3 \cdot 6H_2O$ solution (containing 125 g Fe_2O_3) was added into the slurry under stirring. The pH value of the slurry is 3.0. After stirring for another 45 min, 1.22 kg phosphorus-alumina sol was added into the slurry and stirred evenly. Microspheres with average particle size of $65 \mu m$ were obtained by the spray-drying of the slurry at input temperature of $500^{\circ}C$ and exhaust temperature of $180^{\circ}C$. The catalyst ZJ₁₄ with 30wt% A_6 , 30wt% kaolin, 30wt% Al_2O_3 , 2.5wt% Fe additive (calculated by Fe_2O_3) and 7.5wt% P additive (calculated by P_2O_5) was obtained after the calcination of the microspheres at $500^{\circ}C$ for 1 h.

The XRD pattern of this catalyst is shown in Figure 4 as line o, in which the diffraction peaks at $2\theta=16.30^{\circ}$, $2\theta=26.12^{\circ}$ and $2\theta=30.92^{\circ}$ are the characteristic diffraction peaks of FePO species.

Example 15

1.25 kg A_7 (dry basis), 1 kg kaolin (dry basis), 1.65 kg pseudoboehmite (dry basis), 7.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min, then 1 L aqueous $FeCl_3 \cdot 6H_2O$ solution (having 250 g Fe_2O_3) was added into the slurry under stirring. The pH value of the slurry is 3.0 adjusted by the dosage of HCl. After stirring for another 30 min, 465 g $(NH_4)_2HPO_4$ was added into the slurry and stirred for 30 min. Microspheres with average particle size of $65 \mu m$ were obtained by the spray-drying of

the slurry at input temperature of 500°C and exhaust temperature of 180°C. The catalyst ZJ₁₅ with 25wt% A₇, 20wt% kaolin, 45wt% Al₂O₃, 5wt% Fe additive (calculated by Fe₂O₃) and 5wt% P additive (calculated by P₂O₅) was obtained after the calcination of the microspheres at 500°C for 1 h.

The XRD pattern of this catalyst is shown in Figure 4 as line p, in which the diffraction peaks at 2θ=16.30°, 2θ=26.12° and 2θ=30.99° are the characteristic diffraction peaks of FePO species.

Example 16

2.5 kg A₈ (dry basis), 1.63 kg pseudoboehmite (dry basis), 7.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min, then 1 L aqueous FeCl₃·6H₂O solution (having 270 g Fe₂O₃) was added into the slurry under stirring. The pH value of the slurry is 3.0. The slurry was stirred for another 45 min. Then microspheres with average particle size of 65 μm were obtained by the spray-drying of the slurry at input temperature of 500°C and exhaust temperature of 180°C. The microspheres with 50wt% A₈, 44.6wt% Al₂O₃ and 5.4wt% Fe additive (calculated by Fe₂O₃) were obtained after calcination at 500°C for 1 h.

1 kg microspheres obtained above (dry basis), 10 L deionized water and 210 g (NH₄)₂HPO₄ were heated to 60°C under stirring and reacted for 20 min. The slurry was vacuum-filtrated and dried. The catalyst ZJ₁₆ with 45wt% A₈, 40.1wt% Al₂O₃, 4.9wt% Fe additive (calculated by Fe₂O₃) and 10wt% P additive (calculated by P₂O₅) was obtained after calcination at 500°C for 2 h.

The XRD pattern of this catalyst is shown in Figure 5 as line q, in which the diffraction peaks at 2θ=16.38°, 2θ=26.17° and 2θ=30.93° are the characteristic diffraction peaks of FePO species.

Example 17

The catalyst was prepared according to the method of Example 1,

but the difference is that A₁ is replaced by A₃ with same weight. The catalyst ZJ₁₇ was obtained with 35wt% A₃, 28wt% kaolin, 27.5wt% Al₂O₃, 2.0wt% Fe additive (calculated by Fe₂O₃) and 7.5wt% P additive (calculated by P₂O₅).

5 The XRD pattern of this catalyst is shown in Figure 5 as line r, in which the diffraction peaks at $2\theta=16.25^\circ$, $2\theta=26.12^\circ$ and $2\theta=30.92^\circ$ are the characteristic diffraction peaks of FePO species.

Example 18

10 The catalyst was prepared according to the method of Example 1, but the difference is that A₁ is replaced by A₆ with same weight. The catalyst ZJ₁₈ was obtained with 35wt% A₆, 28wt% kaolin, 27.5wt% Al₂O₃, 2.0wt% Fe additive (calculated by Fe₂O₃) and 7.5wt% P additive (calculated by P₂O₅).

15 The XRD pattern of this catalyst is shown in Figure 5 as line s, in which the diffraction peaks at $2\theta=16.31^\circ$, $2\theta=26.13^\circ$ and $2\theta=30.91^\circ$ are the characteristic diffraction peaks of FePO species.

Example 19

20 The catalyst was prepared according to the method of Example 1, but the difference is that A₁ is replaced by A₈ with same weight. The catalyst ZJ₁₉ was obtained with 35wt% A₈, 28wt% kaolin, 27.5wt% Al₂O₃, 2.0wt% Fe additive (calculated by Fe₂O₃) and 7.5wt% P additive (calculated by P₂O₅).

25 The XRD pattern of this catalyst is shown in Figure 5 as line t, in which the diffraction peaks at $2\theta=16.45^\circ$, $2\theta=26.12^\circ$ and $2\theta=30.92^\circ$ are the characteristic diffraction peaks of FePO species.

30 Comparative examples 1~5 are used to explain the preparation of comparative catalysts.

Comparative Example 1

This comparative example is used to explain the preparation of comparative catalyst containing modified ZSM-5 zeolite (sample A₁) and P additive, but without metal additive of Group VIIIB.

1.75 kg A₁ (dry basis), 1.5 kg kaolin (dry basis), 0.65 kg pseudoboehmite (dry basis), 7.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min. Then 36wt% HCl was added into the slurry under stirring. The dosage of HCl results in a pH value of the slurry of 3.0. After stirring for another 45 min, 1.22 kg phosphorus-alumina sol was added into the slurry and stirred evenly. Microspheres with average particle size of 65 μm were obtained by the spray-drying of the slurry at input temperature of 500 °C and exhaust temperature of 180°C. The comparative catalyst CB₁ with 35wt% A₁, 30wt% kaolin, 27.5wt% Al₂O₃ and 7.5wt% P additive (calculated by P₂O₅) was obtained after the calcination of the microspheres at 500°C for 1 h.

The XRD pattern of this catalyst is shown in Figure 1 as line c, in which the diffraction peak at 2θ=18.50°~23.65° is the characteristic diffraction peak of AlPO₄ species.

Comparative Example 2

This comparative example is used to explain the preparation of comparative catalyst containing modified ZSM-5 zeolite (sample A₁), but without metal additive of Group VIIIB and P additive.

1.75 kg A₁ (dry basis), 1.5 kg kaolin (dry basis), 1.15 kg pseudoboehmite (dry basis), 7.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min. Then 36wt% HCl was added into the slurry under stirring. The dosage of HCl results in a pH value of the slurry of 3.0. The slurry was stirred for another 45 min. Microspheres with average particle size of 65 μm were obtained by the spray-drying of the slurry at input temperature of 500 °C and exhaust temperature of 180°C. The comparative catalyst CB₂ with 35wt% A₁, 30wt% kaolin and 35wt% Al₂O₃ was obtained after

the calcination of the microspheres at 500°C for 1 h.

The XRD pattern of this catalyst is shown in Figure 1 as line d.

Comparative Example 3

5 This comparative example is used to explain the preparation of comparative catalyst containing conventional ZRP-5 zeolite.

The catalyst was prepared according to the method of Comparative Example 2, but the difference is that A₁ is replaced by ZRP-5 zeolite with same weight. The comparative catalyst CB₃ was
10 obtained with 35wt% ZRP-5 zeolite, 30wt% kaolin and 35wt% Al₂O₃.

Comparative Example 4

This comparative example is used to explain the preparation of comparative catalyst containing conventional ZRP-5 zeolite and P
15 additive.

The catalyst was prepared according to the method of Example 1, but the difference is that A₁ is replaced by ZRP-5 zeolite with same weight. The comparative catalyst CB₄ was obtained with 35wt% ZRP-5 zeolite, 30wt% kaolin, 35wt% Al₂O₃ and 5wt% P additive not
20 including the P of ZRP-5 zeolite.

Comparative Example 5

This comparative example is used to explain the preparation of comparative catalyst containing modified ZSM-5 zeolite (sample A₁)
25 and metal additive of Group VIIIB, but without P additive.

1.75 kg A₁ (dry basis), 1.5 kg kaolin (dry basis), 0.9 kg pseudoboehmite (dry basis), 6.2 kg deionized water and 2.79 kg alumina sol were mixed together and stirred for 120 min, then 1 L aqueous FeCl₃·6H₂O solution (having 250 g Fe₂O₃) was added into the
30 slurry under stirring. The pH value of the slurry is 3.0. The slurry was stirred for another 45 min. Then microspheres with average particle size of 65 μm were obtained by the spray-drying of the slurry at input

temperature of 500 °C and exhaust temperature of 180 °C. The comparative catalyst CB₅ with 35wt% A₁, 30wt% kaolin, 30wt% Al₂O₃ and 5wt% Fe additive (calculated by Fe₂O₃) was obtained after the calcination of the microspheres at 500 °C for 1 h.

5 The XRD pattern of this catalyst is shown in Figure 1 as line b, in which the diffraction peaks at $2\theta=24.11^\circ$, $2\theta=33.08^\circ$, $2\theta=35.58^\circ$ and $2\theta=49.40^\circ$ are the characteristic diffraction peaks of Fe₂O₃ species.

Examples 20~38

10 Examples 20~38 are used to explain the method supplied by this invention employed on the fixed fluidized-bed reactor.

30 g Catalysts ZJ₁-ZJ₁₉ were subjected to aging treatment respectively at 800 °C for 8 h under a 100% steam atmosphere. Then the catalysts ZJ₁-ZJ₁₉ after aging treatment were mixed in different
15 content with the commercial FCC ECAT (industry trademark is MLC-500, and its main properties are listed in Table 1). The catalyst mixture was put into the reactor of a small-scaled fixed fluidized-bed reaction apparatus to proceed the catalytic cracking of the feedstock shown in Table 2 (the properties of the feedstock are shown in Table
20 2).

The composition of catalyst mixtures, reaction condition and reaction results are listed in Table 3, Table 4 and Table 5.

Comparative Examples 6~11

25 Comparative Examples 6~11 are used to explain the comparative method employed on the fixed fluidized-bed reactor.

The catalytic cracking of the same feedstock is proceeded according to the method of Example 20, but the difference is that the catalyst is 100% commercial FCC ECAT or the mixture of CB₁~CB₅
30 and commercial FCC ECAT respectively.

The composition of catalyst mixtures used in the comparative method, reaction condition and reaction results are listed in Table 3.

Table 1

Item	commercial ECAT MLC-500
Metal content, ppm	
Ni/V	9386/1665
Fe/Sb	6503/2673
Ca	1714
MAT	60

Table 2

Feedstock	VGO blended with residuum
Density (20°C), g/cm³	0.9070
Viscosity (100°C), mm²/s	10.41
Freeze point, °C	40
Carbon residue, wt%	3.1
Element analysis, wt%	
C/H	86.39/12.53
S/N	0.8/0.29
Composition, wt%	
Paraffin	56.8
Aromatic	24.2
Colloid	18.2
Bitumen	0.8
Metal content, ppm	
V/Ni	0.8/7.0
Fe/Cu	7.8/0.1
Na	2.6
Distillation, °C	
IBP/5%	241/309
10%/20%	343/387
30%/40%	413/432
50%/60%	450/466
70%/80%	493/535

As seen from Table 3, Table 4 and Table 5, comparing to the method using comparative catalyst, the method supplied by this invention could increase not only the LPG yield of FCC effectively and the octane number of FCC gasoline, but also the concentration of propylene in LPG of FCC dramatically.

Table 3

Example No.	Comparative Example 6	20	Comparative Example 7	21	Comparative Example 8	Comparative Example 9	Comparative Example 10	Comparative Example 11
Catalyst	100% ECAT	10%ZJ ₁ + 90%ECAT	10%CB ₁ + 90%ECAT	10%ZJ ₂ + 90%ECAT	10%CB ₂ + 90%ECAT	10%CB ₃ + 90%ECAT	10%CB ₄ + 90%ECAT	10%CB ₄ + 90%ECAT
Reaction temperature, °C	500	500	500	500	500	500	500	500
WHSV, h ⁻¹	16	16	16	16	16	16	16	16
Catalyst-to-oil, wt/wt	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92
Steam (to crude oil), wt%	0	0	0	0	0	0	0	0
Yields, wt%:								
Dry gas	1.60	1.59	1.47	1.58	1.70	1.60	1.56	2.10
LPG	18.04	23.21	20.58	23.54	21.37	21.03	20.76	21.29
C ₅ ⁺ GLN	43.13	37.30	40.09	38.36	39.55	39.88	39.78	38.60
LCO	17.17	17.84	17.46	17.63	17.10	17.04	17.11	17.18
Bottoms	13.61	13.96	14.83	13.25	13.77	14.34	14.60	13.82
Coke	6.45	6.10	5.57	5.64	6.51	6.12	6.19	7.01
Conversion, wt%	69.23	68.20	67.71	69.11	69.13	68.62	68.30	69.00

LPG+GLN+LCO, wt%	78.34	78.36	78.13	79.53	78.02	77.95	77.65	77.07
Propylene, wt%	5.07	8.41	7.14	8.57	6.87	6.65	6.77	6.91
100xpropylene/LP G	28.13	36.23	34.69	36.41	32.16	31.64	32.62	32.47
PONA, wt%								
Paraffins	33.59	26.39	31.33	26.10	29.69	30.56	29.78	29.58
Olefins	23.89	26.35	24.86	25.27	25.4	24.54	24.93	25.51
Naphthene	8.26	8.99	7.98	9.22	8.2	8.26	8.5	8.33
Aromatics	34.08	38.27	35.66	39.39	36.48	36.38	36.44	36.35
RON(GC)	87.1	89.4	89.8	89.5	89.2	88.9	89.0	89.4
MON(GC)	82.0	82.6	82.7	82.6	82.7	82.7	82.7	82.8

Table 4

Example No.	22	23	24	25	26	77	28	29
Catalyst	10%ZJ ₃ + 90%ECA	10%ZJ ₄ + 90%ECA	10%ZJ ₅ + 90%ECA	12%ZJ ₆ + 88%ECA	10%ZJ ₇ + 90%ECA	8%ZJ ₈ + 92%ECA	15%ZJ ₉ + 85%ECA	15%ZJ ₁₀ + 85%ECA
Reaction temperature, °C	500	500	500	500	500	500	500	500
WHSV, h ⁻¹	16	16	16	16	16	16	16	16
Catalyst-to-oil weight ratio	5.92	5.92	5.92	5.92	5.92	5.92	5.92	5.92
Steam (to crude oil), wt%	0	0	0	0	0	0	0	0
Yields, wt%:								
Dry gas	1.60	1.62	1.45	1.56	1.52	1.41	1.69	1.71
LPG	23.46	24.22	23.58	25.28	22.18	22.26	24.49	23.73
C ₅ ⁺ GLN	38.54	38.75	37.61	36.65	39.78	39.26	35.50	36.16
LCO	17.49	16.89	17.82	17.31	17.38	17.67	18.55	18.29
Bottoms	13.14	12.45	13.89	13.41	13.39	13.59	13.59	14.02
Coke	5.77	6.06	5.65	5.79	5.74	5.80	6.19	6.09
Conversion, wt%	69.37	70.66	68.29	69.28	69.23	68.74	67.87	67.69

LPG+GLN+LC	79.48	79.86	79.01	79.24	79.35	79.20	78.54	78.18
O, wt%								
Propylene, wt%	8.47	8.66	8.44	9.12	8.07	7.90	9.05	8.53
100×propylene/L								
PG	36.11	35.74	35.79	36.09	36.39	35.49	36.94	35.94
PONA, wt%								
Paraffins	25.85	25.06	24.87	26.37	26.85	24.26	28.07	28.36
Olefins	23.22	26.1	26.93	26.08	23.73	23.92	27.19	27.20
Naphthene	8.62	8.64	8.85	8.53	8.63	8.54	8.66	8.28
Aromatics	42.14	40	39.36	39.02	40.67	41.23	36.09	36.17
RON(GC)	90.0	89.9	89.5	89.6	89.9	89.5	89.7	89.6
MON(GC)	82.7	82.8	82.6	82.8	82.8	82.7	82.7	82.5

Table 5

Example No.	30	31	32	33	34	35	36	37	38
Catalyst	12%ZJ ₁₁ + 88%ECAT	10%ZJ ₁₂ + 90%ECAT	6%ZJ ₁₃ + 94%ECAT	10%ZJ ₁₄ + 90%ECAT	12%ZJ ₁₅ + 88%ECAT	4%ZJ ₁₆ + 96%ECAT	8%ZJ ₁₇ + 92%ECAT	8%ZJ ₁₈ + 92%ECAT	6%ZJ ₁₉ + 92%ECAT
Reaction temperature, °C	500	500	510	500	490	520	490	500	520
WHSV, h ⁻¹	16	16	10	16	20	10	20	30	10
Catalyst-to-oil weight ratio	5.0	4.5	7.0	5.92	5.0	6.5	5.5	7.0	6.5
Steam (to crude oil), wt%	5	5	5	5	5	10	10	10	10
LPG, wt%	23.41	23.06	24.62	22.78	23.78	22.38	22.56	24.19	23.56
Propylene, wt%	8.41	8.33	9.03	8.15	8.58	7.99	8.06	8.79	8.49
100×propylene/ LPG	35.91	36.12	36.68	35.79	36.09	35.70	35.71	36.34	36.04
Gasoline									
Olefins, wt%	23.82	23.42	26.1	26.91	26.18	23.61	23.81	27.25	27.81
RON (GC)	90.1	90.1	89.9	89.7	89.6	89.8	89.5	89.8	89.7
MON (GC)	82.8	82.5	82.8	82.6	82.7	82.7	82.6	82.8	82.7

Examples 39~47

Examples 39~47 are used to explain the method supplied by this invention employed on the riser reactor.

Catalysts ZJ₁-ZJ₅, ZJ₁₀, ZJ₁₁, ZJ₁₄ and ZJ₁₆ were subjected to aging treatment respectively at 800°C for 8 h under a 100% steam atmosphere. Then the catalysts ZJ₁-ZJ₅, ZJ₁₀, ZJ₁₁, ZJ₁₄ and ZJ₁₆ after aging treatment were mixed in different contents with MLC-500 commercial ECAT. The catalyst mixture was passed into a small-scaled FCC riser reactor continually, at the same time the feedstock shown in Table 2 or the feedstock shown in Table 2 with steam was also passed into continually, which results in the contact of the VGO and the catalyst mixture. Then the catalyst and the reaction product were separated. The separated catalyst was passed into the regenerator to be regenerated, and then the regenerated catalyst was passed back to the riser reactor. The composition of catalyst mixtures (wt%), reaction condition and reaction results are listed in Table 6 and Table 7.

Comparative Examples 12~16

Comparative Examples 12~16 are used to explain the comparative method employed on the riser reactor by using comparative catalyst.

The catalytic cracking of the same feedstock is proceeded according to the method of Example 39, but the difference is that the catalyst mixture is replaced by 100% commercial FCC ECAT, mixture of CB₁ and industry FCC ECAT, mixture of CB₂ and industry FCC ECAT, mixture of CB₃ and commercial FCC ECAT and mixture of CB₄ and commercial FCC ECAT respectively. The composition of catalyst mixtures used in comparative method, reaction condition and reaction results are listed in Table 6.

The results of Table 6 and Table 7 reveal that, comparing to the comparative method using comparative catalyst, the method supplied by this invention could increase not only the LPG yield of FCC effectively and the octane number of FCC gasoline, but also the

concentration of propylene in LPG of FCC dramatically.

Table 6

Example No.	Comparative Example 12	39	Comparative Example 13	40	Comparative Example 14	41	Comparative Example 15	Comparative Example 16
Catalyst	100% ECAT	5%ZJ ₁ + 95% ECAT	5%CB ₁ + 95% ECAT	5%ZJ ₂ + 95% ECAT	5%CB ₂ + 95% ECAT	5%ZJ ₃ + 95% ECAT	5%CB ₃ + 95% ECAT	5 CB ₄ +95% ECAT
Reaction time, s	2.8							
Regeneration temperature, °C	670							
Reaction temperature, °C	500							
Catalyst-to-oil	5.0							
Steam	Corresponding to 10wt% of the crude oil							
Yields, wt%:								
Dry gas	1.73	1.61	1.78	1.68	1.70	1.65	1.76	1.71
LPG	11.95	17.23	14.71	17.03	14.27	16.97	14.03	14.23
C ₅ ⁺ GLN	45.71	40.29	42.61	40.46	42.57	41.25	42.80	43.16
LCO	17.09	17.14	17.31	17.30	17.83	17.18	17.88	17.28
Bottoms	17.49	17.78	17.58	17.57	17.53	16.94	17.51	17.61
Coke	6.03	5.95	6.01	5.96	6.10	6.01	6.02	6.01
Conversion,	65.42	65.08	65.11	65.13	64.64	65.88	64.61	65.11

Table 7

Example No.	42	43	44	45	46	47
Catalyst	5%ZJ ₄ ⁺ 95%ECAT	5%ZJ ₅ ⁺ 95%ECAT	12%ZJ ₁₁ ⁺ 88%ECAT	8%ZJ ₁₄ ⁺ 92%ECAT	3%ZJ ₁₆ ⁺ 97%ECAT	15%ZJ ₁₀ ⁺ 85%ECAT
Reaction time, s	2.5	2.8	1.5	3.5	3.0	3.0
Regeneration temperature, °C	695	670	670	695	670	670
Reaction temperature, °C	490	500	500	510	515	495
Catalyst-to-oil	6	5.0	4	5.5	5	6.5
Steam (corresponding to wt% of the crude oil)	10	10	5	15	0	10
Yields, wt%:						
Dry gas	1.69	1.63	1.71	1.70	1.82	1.89
LPG	18.75	17.01	21.18	19.15	15.83	22.07
C ₅ ⁺ GLN	39.28	40.36	35.17	40.73	42.41	35.31
LCO	17.37	17.25	17.91	15.79	17.23	16.98
Bottoms	16.71	17.84	18.01	16.52	16.70	17.53
Coke	6.20	5.91	6.02	6.11	6.01	6.22
Conversion, wt%	65.92	64.91	64.08	67.69	66.07	65.49
Propylene, wt%	7.10	6.32	8.40	7.29	5.85	8.44

100×propylene/LPG	37.87	37.15	39.68	38.05	36.98	38.25
PONA, wt%						
Paraffins	27.61	24.31	23.16	26.46	24.31	27.51
Olefins	36.00	40.37	43.23	37.85	40.27	34.97
Naphthene	8.11	8.86	8.06	8.06	8.65	8.45
Aromatics	28.28	26.42	25.52	27.63	26.74	29.06
RON(tested)	90.1	90.1	90.5	89.2	90.1	90.1
MON(tested)	80.0	80.2	80.4	80.4	79.8	80.4

Claims

1 . A catalyst, which comprises, calculated by dry basis, 10~65wt% ZSM-5 zeolite, 0~60wt% clay, 15~60wt% inorganic oxide binder, 0.5~15wt% one or more metal additives selected from the metals of Group VIIIB and 2~25wt% P additive in which the metal additive and the P additive are calculated by oxide.

2 . A catalyst according to claim 1 in which the catalyst is consisted of, calculated by dry basis, 20~50wt% ZSM-5 zeolite, 10~45wt% clay, 25~50wt% inorganic oxide binder, 1.0~10wt% one or more metal additives selected from the metals of Group VIIIB and 5~15wt% P additive.

3 . A catalyst according to claim 1 in which the ZSM-5 zeolite is modified by P and one of the metals selected from Fe, Co or Ni, the anhydrous chemical expression, calculated by oxide, is $(0\sim0.3)Na_2O \cdot (0.5\sim5)Al_2O_3 \cdot (1.3\sim10)P_2O_5 \cdot (0.7\sim15)M_xO_y \cdot (70\sim97)SiO_2$, in which x is the atom number of M and Y is a number needed to satisfy the oxidation state of M.

4 . A catalyst according to claim 3 in which the anhydrous chemical expression of ZSM-5 zeolite, calculated by oxide, is $(0\sim0.2)Na_2O \cdot (0.9\sim3.5)Al_2O_3 \cdot (1.5\sim7)P_2O_5 \cdot (0.9\sim10)M_xO_y \cdot (82\sim92)SiO_2$.

5 . A catalyst according to claim 3 in which M is Fe.

6 . A catalyst according to claim 1 or 2 in which the metal of Group VIIIB is selected from one or more of Fe, Co and Ni.

7 . A catalyst according to claim 6 in which the metal of Group VIIIB is Fe.

8 . A catalyst according to claim 7 in which the XRD patterns comprise at least the characteristic diffraction peaks of FePO species at $2\theta=16.35\pm0.5^\circ$, $2\theta=26.12\pm0.5^\circ$ and $2\theta=30.94\pm0.5^\circ$.

9 . A catalyst according to claim 1 in which the clay is selected from one or mixture of more than one of kaolin, metakaolin, diatomite, sepiolite, attapulgite clay, montmorillonite and rectorite.

10 . A catalyst according to claim 1 in which the inorganic oxide binder is selected from one or mixture of more than one of pseudoboehmite, alumina sol, silica-alumina sol, water glass and phosphorus-alumina sol.

5 11 . A catalyst according to claim 1 in which the inorganic oxide binder is selected from one or mixture of more than one of pseudoboehmite, alumina sol and phosphorus-alumina sol.

12 . A method for cracking hydrocarbons in which the hydrocarbons are contacted with a catalyst mixture containing the
10 catalysts disclosed in one of claims 1-11 under the cracking condition, and then the cracked products are collected.

13 . A method according to claim 12 in which the contact procedure of hydrocarbons and the catalyst mixture containing the catalysts disclosed in one of claims 1-11 is proceeded on a fixed-bed
15 reactor, a fluidized-bed reactor or a moving-bed reactor, the reaction temperature is 400~650°C, the catalyst-to-oil weight ratio is 1~25 and the weight hourly space velocity is 10~120h⁻¹.

14 . A method according to claim 13 in which the reaction temperature is 420~600°C, the catalyst-to-oil weight ratio is 3~20 and
20 the weight hourly space velocity is 15~80h⁻¹.

15 . A method according to claim 12 in which the contact procedure of hydrocarbons and the catalyst mixture containing the catalysts disclosed in one of claims 1-11 is proceeded on a riser reactor, the cracking condition including a reaction temperature of 400~650°C,
25 a catalyst-to-oil weight ratio of 1~25 and a reaction time of 0.5~15s.

16 . A method according to claim 15 in which the reaction temperature is 420~600°C, the catalyst-to-oil weight ratio is 3~20 and the reaction time is 0.5~10s.

17 . A method according to claim 12 in which the content of the
30 catalysts disclosed in one of claims 1-11 in the catalyst mixture is 1~30wt%.

18 . A method according to claim 17 in which the content of the

catalysts disclosed in one of claims 1-11 is 3~20wt%.