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(57) **Abrégé/Abstract:**

Process for the preparation of a catalyst comprising the steps of (a) preparing a slurry comprising clay, zeolite, a sodium-free silica source, quasi-crystalline boehmite, and micro-crystalline boehmite, provided that the slurry does not comprise peptised quasi-crystalline boehmite, (b) adding a monovalent acid to the slurry, (c) adjusting the pH of the slurry to a value above 3, and (d) shaping the slurry to form particles. This process results in attrition resistant catalysts with a good accessibility.



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(54) Title: FCC CATALYST, ITS PREPARATION AND USE

(57) Abstract: Process for the preparation of a catalyst comprising the steps of (a) preparing a slurry comprising clay, zeolite, a sodium-free silica source, quasi-crystalline boehmite, and micro-crystalline boehmite, provided that the slurry does not comprise peptised quasi-crystalline boehmite, (b) adding a monovalent acid to the slurry, (c) adjusting the pH of the slurry to a value above 3, and (d) shaping the slurry to form particles. This process results in attrition resistant catalysts with a good accessibility.

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FCC CATALYST, ITS PREPARATION AND USE

The present invention relates to a process for the preparation of a catalyst, catalysts obtainable by this process, and their use in, e.g., fluid catalytic cracking
5 (FCC).

A common challenge in the design and production of heterogeneous catalysts is to find a good compromise between the effectiveness and/or accessibility of the active sites and the effectiveness of the immobilising matrix in giving the catalyst
10 particles sufficient physical strength, i.e. attrition resistance.

The preparation of attrition resistant catalysts is disclosed in several prior art documents.

US 4,086,187 discloses a process for the preparation of an attrition resistant
15 catalyst by spray-drying an aqueous slurry prepared by mixing (i) a faujasite zeolite with a sodium content of less than 5 wt% with (ii) kaolin, (iii) peptised pseudoboehmite, and (iv) ammonium polysilicate.

The attrition resistant catalysts according to US 4,206,085 are prepared by spray-
20 drying a slurry prepared by mixing two types of acidified pseudoboehmite, zeolite, alumina, clay, and either ammonium polysilicate or silica sol.

GB 1 315 553 discloses the preparation of an attrition resistant hydrocarbon conversion catalyst comprising a zeolite, a clay, and an alumina binder. The
25 catalyst is prepared by first dry mixing the zeolite and the clay, followed by adding an alumina sol. The resulting mixture is then mixed to a plastic consistency, which requires about 20 minutes of mixing time. In order to form shaped particles, the plastic consistency is either pelletised or extruded, or it is mixed with water and subsequently spray-dried.

The alumina sol disclosed in this British patent specification comprises aluminium hydroxide and aluminium trichloride in a molar ratio of 4.5 to 7.0 (also called aluminium chlorohydrol).

- 5 US 4,458,023 relates to a similar preparation procedure, which is followed by calcination of the spray-dried particles. During calcination, the aluminium chlorohydrol component is converted into an alumina binder.

10 WO 96/09890 discloses a process for the preparation of attrition resistant fluid catalytic cracking catalysts. This process involves the mixing of an aluminium sulphate/silica sol, a clay slurry, a zeolite slurry, and an alumina slurry, followed by spray-drying. During this process, an acid- or alkaline-stable surfactant is added to the silica sol, the clay slurry, the zeolite slurry, the alumina slurry and/or the spray-drying slurry.

15

CN 1247885 also relates to the preparation of a spray-dried cracking catalyst. This preparation uses a slurry comprising an aluminous sol, pseudoboehmite, a molecular sieve, clay, and an inorganic acid. In this process the aluminous sol is added to the slurry before the clay and the inorganic acid are added, and the
20 molecular sieve slurry is added after the inorganic acid has been added. According to one embodiment, pseudoboehmite and aluminium sol are first mixed, followed by addition of the inorganic acid. After acidification, the molecular sieve is added, followed by kaolin.

25 WO 02/098563 discloses a process for the preparation of an FCC catalyst having both a high attrition resistance and a high accessibility. The catalyst is prepared by slurrying zeolite, clay, and boehmite, feeding the slurry to a shaping apparatus, and shaping the mixture to form particles, characterised in that just before the shaping step the mixture is destabilised. This destabilisation is achieved by, e.g.,

temperature increase, pH increase, pH decrease, or addition of gel-inducing agents such as salts, phosphates, sulphates, and (partially) gelled silica. Before destabilisation, any peptisable compounds present in the slurry must have been well peptised.

5

Although the catalyst according to the latter document has a relatively high attrition resistance and accessibility, it has now been found that the accessibility/attrition resistance ratio can be further improved.

This further improvement is achieved by the process according to the invention,
10 which process comprises the steps of:

- a) preparing a slurry comprising clay, zeolite, a sodium-free silica source, quasi-crystalline boehmite, and micro-crystalline boehmite, provided that the slurry does not comprise peptised quasi-crystalline boehmite,
- b) adding a monovalent acid to the slurry,
- 15 c) adjusting the pH of the slurry to a value above 3, and
- d) shaping the slurry to form particles,

In contrast to conventional processes where quasi-crystalline boehmites (e.g. pseudoboehmites) always have been peptised before addition to the zeolite-
20 containing slurry, the process according to the invention adds non-peptised quasi-crystalline boehmite (QCB). Acid is only added after QCB addition, i.e. to a slurry that also comprises zeolite and clay.

Further, a sodium-free silica source is used. Examples of sodium-free silica
25 sources are (poly)silicic acid, sodium-free silica sol, potassium silicate, lithium silicate, calcium silicate, magnesium silicate, barium silicate, strontium silicate, zinc silicate, phosphorus silicate, and borium silicate. Examples of suitable organic silicates are silicones (polyorganosiloxanes such as polymethylphenylsiloxane and polydimethylsiloxane) and other compounds containing Si-O-C-O-Si structures,

and precursors thereof such as methyl chlorosilane, dimethyl chlorosilane, trimethyl chlorosilane, and mixtures thereof.

Preferred sodium-free silica sources are (poly)silicic acid and sodium-free silica sol.

5

Further, the process according to the present invention leads to the preparation of catalysts comprising both micro- and quasi-crystalline boehmites with an attrition resistance that is sufficient for use in FCC.

Micro-crystalline boehmite (MCB) is a suitable metal passivator, in particular for Ni
10 contaminants. However, up to now the preparation of MCB-containing FCC catalyst particles has been unsuccessful, because MCB is difficult to bind with conventional FCC-type binders, leading to catalyst particles with unacceptable attrition. With the process according to the present invention, MCB-containing catalysts with satisfactory attrition resistance are obtained.

15

Boehmite

The term "boehmite" is used in the industry to describe alumina hydrates which exhibit X-ray diffraction (XRD) patterns close to that of aluminium oxide-hydroxide [AlO(OH)]. Further, the term boehmite is generally used to describe a wide range
20 of alumina hydrates which contain different amounts of water of hydration, have different surface areas, pore volumes, specific densities, and exhibit different thermal characteristics upon thermal treatment. Yet their XRD patterns, although they exhibit the characteristic boehmite [AlO(OH)] peaks, usually vary in their widths and can also shift in their location. The sharpness of the XRD peaks and
25 their location has been used to indicate the degree of crystallinity, crystal size, and amount of imperfections.

Broadly, there are two categories of boehmite aluminas: quasi-crystalline boehmites (QCBs) and micro-crystalline boehmites (MCBs).

In the state of the art, quasi-crystalline boehmites are also referred to as pseudo-boehmites and gelatinous boehmites. Usually, these QCBs have higher surface areas, larger pores and pore volumes, and lower specific densities than MCBs. They disperse easily in water or acids, have smaller crystal sizes than MCBs, and
5 contain a larger number of water molecules of hydration. The extent of hydration of QCB can have a wide range of values, for example from about 1.4 up to about 2 moles of water per mole of Al, intercalated usually orderly or otherwise between the octahedral layers.

DTG (differential thermogravimetry) indicates that the major amount of water is
10 released from QCBs at a much lower temperature than from MCBs.

The XRD Patterns of QCBs show quite broad peaks and their half-widths (i.e. the widths of the peaks at half-maximum intensity) are indicative of the crystal sizes as well as degree of crystal perfection.

Some typical commercially available QCBs are Pural®, Catapal®, and Versal®
15 products.

Microcrystalline boehmites are distinguished from the QCBs by their high degree of crystallinity, relatively large crystal size, very low surface areas, and high densities. Contrary to QCBs, MCBs show XRD patterns with higher peak intensities and very
20 narrow half-widths. This is due to their relatively small number of intercalated water molecules, large crystal sizes, the higher degree of crystallization of the bulk material, and the smaller amount of crystal imperfections. Typically, the number of water molecules intercalated can vary in the range from about 1 up to about 1.4 per mole of Al.

25 A typical commercially available MCB is Condea's P-200®.

MCBs and QCBs are characterised by powder X-ray reflections. The ICDD contains entries for boehmite and confirms that reflections corresponding to the (020), (021), and (041) planes would be present. For copper radiation, such

reflections would appear at 14, 28, and 38 degrees 2-theta. The exact position of the reflections depends on the extent of crystallinity and the amount of water intercalated: as the amount of intercalated water increases, the (020) reflection moves to lower values, corresponding to greater d-spacings. Nevertheless, lines
5 close to the above positions would be indicative of the presence of one or more types of boehmite phases.

For the purpose of this specification we define quasi-crystalline boehmites as having a (020) reflection with a full width at half height (FWHH) of 1.5° or greater than $1.5^\circ 2\theta$. Boehmites having a (020) reflection with a FWHH of smaller than 1.5°
10 2θ are considered micro-crystalline boehmites.

Overall, the basic, characteristic differences between QCBs and MCBs involve variations in the following: 3-dimensional lattice order, sizes of the crystallites, amount of water intercalated between the octahedral layers, and degree of crystal
15 imperfections.

Zeolite

The zeolite used in the process according to the present invention preferably has a low sodium content (less than 1.5 wt% Na_2O), or is sodium-free. Suitable zeolites
20 to be present in the slurry of step a) include zeolites such as Y-zeolites - including HY, USY, dealuminated Y, RE-Y, and RE-USY - zeolite beta, ZSM-5, phosphorus-activated ZSM-5, ion-exchanged ZSM-5, MCM-22, and MCM-36, metal-exchanged zeolites, ITQs, SAPOs, ALPOs, and mixtures thereof.

25 Clay

Also the clay is preferred to have a low sodium content (less than 0.1 wt% Na_2O), or to be sodium-free.

Suitable clays include kaolin, bentonite, saponite, sepiolite, attapulgite, laponite, hectorite, English clay, anionic clays such as hydrotalcite, and heat- or chemically treated clays such as meta-kaolin.

5 Step a)

- The slurry of step a) is prepared by suspending clay, zeolite, the sodium-free silica source, non-peptised quasi-crystalline boehmite, and micro-crystalline boehmite in water. Optionally, other components may be added, such as aluminium chlorohydrate, aluminium nitrate, Al_2O_3 , $\text{Al}(\text{OH})_3$, anionic clays (e.g. hydrotalcite),
- 10 smectites, sepiolite, barium titanate, calcium titanate, calcium-silicates, magnesium-silicates, magnesium titanate, mixed metal oxides, layered hydroxy salts, additional zeolites, magnesium oxide, bases or salts, and/or metal additives such as compounds containing an alkaline earth metal (for instance Mg, Ca, and Ba), a Group IIIA transition metal, a Group IVA transition metal (e.g. Ti, Zr), a
- 15 Group VA transition metal (e.g. V, Nb), a Group VIA transition metal (e.g. Cr, Mo, W), a Group VIIA transition metal (e.g. Mn), a Group VIIIA transition metal (e.g. Fe, Co, Ni, Ru, Rh, Pd, Pt), a Group IB transition metal (e.g. Cu), a Group IIB transition metal (e.g. Zn), a lanthanide (e.g. La, Ce), or mixtures thereof.
- 20 The clay, zeolite, non-peptised QCB, MCB, sodium-free silicon source, and optional other components can be slurried by adding them to water as dry solids. Alternatively, slurries containing the individual materials are mixed to form the slurry according to step a). It is also possible to add some of the materials as slurries, and others as dry solids.
- 25 Any order of addition of these compounds may be used. It is also possible to combine these compounds all at the same time.

The slurry preferably comprises 10 to 70 wt%, more preferably 15 to 50 wt%, and most preferably 15 to 35 wt% of zeolite.

The slurry preferably comprises 5 to 70 wt%, more preferably 10 to 60 wt%, and most preferably 10 to 50 wt% of clay.

The slurry preferably comprises 1 to 50 wt%, more preferably 2 to 50 wt%, and most preferably 5 to 50 wt% of non-peptised QCB.

- 5 The slurry also comprises 1 to 50 wt%, more preferably 1 to 30 wt%, and most preferably 1 to 20 wt% of MCB.

The slurry further comprises 1 to 35 wt% and more preferably 4 to 18 wt% of sodium-free silicon source.

All weight percentages are based on dry solids content and calculated as oxides.

10

The solids content of the slurry preferably is 10-30 wt%, more preferably 15-30 wt%, and most preferably 15-25 wt%.

Step b)

- 15 In a next step, a monovalent acid is added to the suspension, causing digestion.

Both organic and inorganic monovalent acids can be used, or a mixture thereof. Examples of suitable monovalent acids are formic acid, acetic acid, propionic acid, nitric acid, and hydrochloric acid.

- 20 The acid is added to the slurry in an amount sufficient to obtain a pH lower than 7, more preferably between 2 and 5, most preferably between 3 and 4.

During acid addition, the slurry may be stirred, milled, grinded, high-shear mixed, or treated with ultrasound waves.

- 25 Step c)

If the pH of the slurry of step b) is below 3, the pH of the slurry is subsequently adjusted to a value above 3, more preferably above 3.5, even more preferably above 4, and most preferably about 4.5 or higher. The pH of the slurry is preferably not higher than 7, because slurries with a higher pH can be difficult to handle.

The pH can be adjusted by adding a base (e.g. NaOH or NH₄OH) to the slurry.

However, if after addition of the acid in step b) the pH is 3 or higher, the pH may, but does not have to be raised in step c).

5

The time period between the pH adjustment and shaping step d) preferably is 30 minutes or less, more preferably less than 5 minutes, and most preferably less than 3 minutes.

10 Step d)

Suitable shaping methods include spray-drying, pulse drying, pelletising, extrusion (optionally combined with kneading), beading, or any other conventional shaping method used in the catalyst and absorbent fields or combinations thereof. A preferred shaping method is spray-drying. If the catalyst is shaped by spray-drying,
15 the inlet temperature of the spray-dryer preferably ranges from 300 to 600°C and the outlet temperature preferably ranges from 105 to 200°C.

The catalyst so obtained has exceptionally good attrition resistance and accessibility. Therefore, the invention also relates to a catalyst obtainable by the
20 process according to the invention.

The invention further relates to a catalyst comprising MCB, QCB, silica, zeolite, and clay. Preferably, such a catalyst comprises 1-50 wt%, more preferably 3-40 wt% of QCB, 1 to 25, more preferably 5-25 wt% of MCB, 1-25 wt% silica, 5-50 wt% zeolite, and balance clay (calculated as oxides).

25

These catalysts can be used as FCC catalysts, FCC additives - such as SO_x reduction additives, NO_x reduction additives, CO combustion additives, ZSM-5 additives, or sulphur in gasoline reduction additives – in hydroprocessing catalysts,

alkylation catalysts, reforming catalysts, gas-to-liquid conversion catalysts, coal conversion catalysts, hydrogen manufacturing catalysts, and automotive catalysts. The invention therefore also relates to the use of these catalyst obtainable by the process of the invention as catalyst or additive in fluid catalytic cracking, hydroprocessing, alkylation, reforming, gas-to-liquid conversion, coal conversion, and hydrogen manufacturing, and as automotive catalyst.

EXAMPLES

10 Accessibility measurement

The accessibility of the catalysts prepared according to the Examples below was measured by adding 1 g of the catalyst to a stirred vessel containing 50 g of a 15 g/l Kuwait vacuum gas oil (KVGO) in toluene solution. The solution was circulated between the vessel and a spectrophotometer, in which process the KVGO-concentration was continuously measured.

The accessibility of the catalysts to KVGO was quantified by the Akzo Accessibility Index (AAI). The relative concentration of KVGO in the solution was plotted against the square root of time. The AAI is defined as the initial slope of this graph:

$$20 \quad AAI = -d(C_t/C_0)/d(t^{1/2}) * 100\%$$

In this equation, t is the time (in minutes) and C_0 and C_t denote the concentrations of high-molecular weight compound in the solvent at the start of the experiment and at time t , respectively.

25

Attrition resistance measurement

The attrition resistance of the catalysts was measured by the standard Attrition Test. In this test the catalyst bed resides on an attrition plate with three nozzles. The attrition plate is situated within an attrition tube which is at ambient

temperature. Air is forced to the nozzles and the resulting jets bring about upward transport of catalyst particles and generated fines. On top of the attrition tube is a separation chamber where the flow dissipates, and most particles larger than about 16 microns fall back into the attrition tube. Smaller particles are collected in a collection bag.

This test is conducted after calcination of the catalyst samples at 600°C, and it is first run for 5 hours and the weight percentage of fines collected in the collection bag, based on an imaginary intake of 50 grams, is determined. This is the initial attrition. The test is then conducted for another 15 hours and the weight percentage of fines in this time period (5-20 hours) is determined. This is the inherent attrition. The Attrition Index (AI) is the extrapolated wt% fines after 25 hours. So, the more attrition resistant the catalyst is, the lower the AI value.

Comparative Example 1

An aqueous slurry containing peptisable QCB (13.3 kg) was mixed with water and peptised by acidification with formic acid. The pH of the resulting mixture was 2. The mixture was stirred for 15 minutes. Next, MCB (highly crystalline alumina, 5 kg), zeolite Y slurry (8 kg), kaolin (4.17 kg), sodium-free silica sol (2.4 kg), and water were added and blended with the peptised QCB. The final pH of the slurry was 3.2. The slurry was then sent to a spray-dryer at 1 kg/min, inlet temperature 500°C, and outlet temperature 120°C.

The resulting material comprised 20 wt% zeolite, 24 wt% QCB, 14 wt% MCB, 6% SiO₂, and balance kaolin. The powder had a d₅₀ around 65 µm.

The attrition index (AI), the accessibility index (AAI), and their ratio are indicated in the Table below.

Example 2

An aqueous slurry containing non-peptised but peptisable QCB (13.3 kg), MCB (highly crystalline alumina, 5.4 kg), a zeolite Y slurry (8 kg), kaolin (4.17 kg),

sodium-free silica sol, and water were blended together. Nitric acid was then added to the total reaction mixture to reach pH 3.3. The slurry was then sent to a spray-dryer at 1 kg/min, inlet temperature 500°C, and outlet temperature 120°C.

The resulting material comprised 20 wt% zeolite, 24 wt% QCB, 14 wt% MCB, 6% SiO₂, and balance kaolin. The powder had a d50 around 65 µm.

The attrition index, the accessibility index, and their ratio are indicated in the Table below.

Comparative Example 3

10 An aqueous slurry containing peptisable QCB (16.6 kg) was mixed with water and peptised by acidification with formic acid. The pH of the resulting mixture was 2. The mixture was stirred for 15 minutes. Next, MCB (highly crystalline alumina, 5.4 kg), zeolite Y slurry (7.2 kg), kaolin (4.17 kg), sodium-free silica sol (2.4 kg), and water were added and blended with the peptised QCB. The final pH of the slurry
15 was 3.2. The slurry was then sent to a spray-dryer at 1 kg/min, inlet temperature 500°C, and outlet temperature 120°C.

The resulting material comprised 18 wt% zeolite, 30 wt% QCB, 15 wt% MCB, 4% SiO₂, and balance kaolin. The powder had a d50 around 65 µm.

The attrition index, the accessibility index, and their ratio are indicated in the Table
20 below.

Example 4

An aqueous slurry containing non-peptised but peptisable QCB (16.6 kg), MCB (highly crystalline alumina, 5.4 kg), a zeolite Y slurry (8 kg), kaolin (4.17 kg),
25 sodium-free silica sol, and water were blended together. Nitric acid was then added to the total reaction mixture to reach pH 3.2. The slurry was then sent to a spray-dryer at 1 kg/min, inlet temperature 500°C, and outlet temperature 120°C.

The resulting material comprised 18 wt% zeolite, 30 wt% QCB, 15 wt% MCB, 4% SiO₂, and balance kaolin. The powder had a d50 around 65 µm.

The attrition index, the accessibility index, and their ratio are indicated in the Table below.

Comparative Example 5

- 5 An aqueous slurry containing peptisable QCB (16.6 kg) was mixed with water and peptised by acidification with formic acid. The pH of the resulting mixture was 2. The mixture was stirred for 15 minutes. Next, MCB (highly crystalline alumina, 5.4 kg), zeolite Y slurry (9.6 kg), kaolin (4.17 kg), sodium-free silica sol (2.4 kg), and water were added and blended with the peptised QCB. The final pH of the slurry
- 10 was 3.2. The slurry was then sent to a spray-dryer at 1 kg/min, inlet temperature 500°C, and outlet temperature 120°C.

The resulting material comprised 24 wt% zeolite, 30 wt% QCB, 15 wt% MCB, 4% SiO₂, and balance kaolin. The powder had a d50 around 65 µm.

- The attrition index, the accessibility index, and their ratio are indicated in the Table
- 15 below.

Example 6

- An aqueous slurry containing non-peptised but peptisable QCB (16.6 kg), MCB (highly crystalline alumina, 5.4 kg), a zeolite Y slurry (9.6 kg), kaolin (4.17 kg),
- 20 sodium-free silica sol, and water were blended together. Nitric acid was then added to the total reaction mixture to reach pH 3.3. The slurry was then sent to a spray dryer at 1 kg/min, inlet temperature 500°C, and outlet temperature 120°C.

The resulting material comprised 24 wt% zeolite, 30 wt% QCB, 15 wt% MCB, 4% SiO₂, and balance kaolin. The powder had a d50 around 65 µm.

- 25 The attrition index, the accessibility index, and their ratio are indicated in the Table below.

Table

Example	AI	AAI	AAI/AI
1 (comparative)	18	15	0.8
2	8.1	12	1.5
3 (comparative)	15.8	14	0.9
4	6.8	11	1.6
5 (comparative)	20.2	18	0.9
6	9.5	14	1.5

This Table shows that the process of the present invention results in more attrition
5 resistant catalysts (reduced AI) and a higher AAI/AI ratio compared to a process
which uses pre-peptised boehmite.

CLAIMS

1. Process for the preparation of a catalyst comprising the steps of:
 - a) preparing a slurry comprising clay, zeolite, a sodium-free silica source,
5 quasi-crystalline boehmite, and micro-crystalline boehmite, provided that the
 slurry does not comprise peptised quasi-crystalline boehmite,
 - b) adding a monovalent acid to the slurry,
 - c) adjusting the pH of the slurry to a value above 3, and
 - d) shaping the slurry to form particles.
- 10 2. A process according to claim 1 wherein the sodium-free silica source is
 selected from the group consisting are sodium-free silica sol, polysilicic acid,
 potassium silicate, lithium silicate, calcium silicate, magnesium silicate, barium
 silicate, strontium silicate, zinc silicate, phosphorus silicate, and borium silicate,
15 polyorganosiloxanes, methyl chlorosilane, dimethyl chlorosilane, trimethyl
 chlorosilane, and mixtures thereof.
3. A process according to claim 1 or 2 wherein the pH in step c) is adjusted to a
 value of between 4 and 7.
- 20 4. Catalyst obtainable by the process according to any one of the preceding
 claims.
5. Catalyst comprising micro-crystalline boehmite, quasi-crystalline boehmite,
25 zeolite, and silica.
6. Use of the catalyst according to either of claims 4 or 5 in fluid catalytic cracking,
 hydroprocessing, alkylation, reforming, gas-to-liquid conversion, coal
 conversion, and hydrogen manufacturing, and as automotive catalyst.