

## **Extruded Cu-Al-Mn hydrogenation catalyst**

The invention relates to shaped Cu-Al-Mn catalyst bodies in extruded form, and to processes for producing them. The shaped catalyst bodies are suitable for hydrogenating organic compounds which contain a carbonyl function, more particularly for hydrogenating aldehydes, ketones, and also carboxylic acids and/or their esters. A preferred hydrogenation is that of fatty acids and/or their esters, such as fatty acid methyl esters, to the corresponding alcohols, and of dicarboxylic anhydrides, such as maleic anhydride (MAN), or esters of di-acids, to di-alcohols, such as butanediol.

### **Background of the invention**

Catalysts in tablet form are generally used for hydrogenation reactions. These tablets are notable for high mechanical stability, a property determinable in the form of the side crushing strength. The stability comes about as a result of a relatively high pressure during tableting. As a result, the powder starting material is highly compressed, producing tablets having a relatively high bulk density. The high compression also reduces the pore volume and hence restricts access to the active centers. Only part of the active metal components, therefore, are available for the reaction.

Already disclosed in the prior art are catalysts in extrudate form where the powder starting material is processed by addition of a defined amount of suitable binders and by means of extrusion to give the corresponding shaped catalyst bodies. Extrudates customarily have a greater pore volume than the tablets produced from the same powder starting material.

The catalysts in extrudate form that are known in the prior art differ from the catalysts of the invention in particular in the composition, such as the metals and

types of binder used, for example, and also in the physicochemical properties.

US 5 977 010 describes a shaped catalyst body which  
5 comprises (i) at least one metal from the group consisting of copper, manganese, zinc, nickel, cobalt, and iron, and also (ii) calcium silicate and (iii) at least one clay material. These shaped catalysts are used for hydrogenating aldehydes, ketones, carboxylic  
10 acids, and carboxylic esters.

WO 92/10290 discloses shaped bodies of a copper chromite catalyst formed from a mixture of about 20 to 80 wt% of copper chromite and 20 to 80 wt% of at least  
15 one extrudable, inorganic binder material. The catalysts have a surface area of 20 to 225 m<sup>2</sup>/g, and the total pore volume is between 0.35 and 1 cm<sup>3</sup>/g. This document describes a process for producing the shaped copper chromite catalyst by extrusion of a mixture of  
20 copper chromite, an extrudable inorganic binder material, a peptizing agent, and water, and calcining of the extrudate. The shaped bodies obtained are used for hydrogenating aldehydes, ketones, carboxylic acids, and carboxylic esters.

25 US 4 666 879 describes an extruded copper chromite-aluminum oxide catalyst which is produced by mixing 40 to 82 wt% of copper chromite and 18 to 60% of an extrudable aluminum oxide, typically having a  
30 pseudoboehmite or alpha-hydroxy-boehmite structure. After being calcined, the extruded catalyst can be used for hydrogenating various carbonyl compounds in the liquid or gas phase. The catalyst has a surface area of between 20 and 225 m<sup>2</sup>/g and a bulk density of between  
35 0.70 and 1.20 g/cm<sup>3</sup>.

WO 2006/005505 describes a process for hydrogenating organic, carbonyl-functional compounds using copper-containing catalyst tablets or catalyst extrudates

having a diameter of < 2.5 mm. The catalysts are produced by shaping and subsequently calcining a mixture of 50 to 80 wt% of copper oxide, 15 to 35 wt% of aluminum oxide, 2 to 20 wt% of lanthanum oxide, and  
5 copper platelets.

In the dissertation by Steffen P. Miller, University of Karlsruhe (TH), 2005, Cu/Zn catalysts in extruded form are described that are produced using boehmite-based  
10 binders.

WO 2005/058491 discloses CuO/Al<sub>2</sub>O<sub>3</sub>-containing shaped catalyst bodies in extrudate form. The catalysts are produced by mixing boehmite, which has undergone  
15 incipient etching with formic acid, with a CuO/Al<sub>2</sub>O<sub>3</sub>-containing active material and water. The mixture is then extruded to strands which are calcined at 600°C. The catalysts have a bulk density of between 790 and 960 g/l and pore volumes in the range from 0.31 to  
20 0.59 cm<sup>3</sup>/g.

The mechanical stability of extrudates is generally lower than that of catalyst tablets, as manifested in a low side crushing strength, for example. Furthermore,  
25 the binders used in extrudates frequently have an adverse effect on catalyst performance. Major influencing parameters are the inherent activity of the binder matrix, change in the surface acidity, and diffusion effects in the matrix. These effects are  
30 described for example by K.P. de Jong in "Syntheses of solid catalysts", 2009, Wiley-VCH, p. 175, or in the dissertation by J. Freiding: "Extrusion of technical ZSM-5 catalysts and their application in the MTO process", University of Karlsruhe (TH), 2009,  
35 especially section 2.5 and section 5.6. In DE 10 2006 058800, therefore, shaped catalyst bodies which are extremely pure are explicitly claimed, in order to prevent adverse effects arising from the catalyst matrix.

It is an object of the present invention to provide shaped catalyst bodies which do not have the aforementioned drawbacks of catalyst tablets and catalyst extrudates, thus having a substantially higher pore volume and a significantly lower bulk density in conjunction with at least comparable stability and activity in comparison to conventional, tableted catalysts.

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This object is achieved in accordance with the invention by using, when processing powder catalyst material into extrudates, specific binders which lead to stable shaped catalyst bodies. Through the processing of the powder catalyst material into extrudates using binders which lead to stable shaped bodies and at the same time generate a high pore volume, it has been possible to produce shaped catalyst bodies which, for comparable stability, have a substantially higher pore volume than the conventional, tableted catalysts.

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#### **Summary of the invention**

25 The invention relates to a shaped catalyst body in extruded form, comprising Cu in an amount in the range of 20 - 43 wt%, preferably in the range of 25 - 42 wt%, Al in an amount in the range of 20 - 40 wt%, preferably in the range of 25 - 34 wt%, and Mn in an amount in the range of 1 - 10 wt%, preferably in the range of 2 - 8 wt%, more preferably in the range of 3 - 6 wt%, based on the total weight of the shaped catalyst body in extruded form,

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35 wherein the shaped catalyst body has a pore volume in the range from 250 to 700 mm<sup>3</sup>/g, preferably in the range from 400 to 650 mm<sup>3</sup>/g, more preferably in the range from 450 to 600 mm<sup>3</sup>/g, determined by mercury intrusion to DIN 66133.

The invention further relates to a process for producing Cu-, Al-, and Mn-containing shaped catalyst bodies (shaped Cu-Al-Mn catalyst bodies) in extruded form, the process comprising the following steps:

(a) combining (i) at least one aqueous solution of copper compounds, aluminum compounds, manganese compounds, and optionally transition metal compounds and (ii) at least one aqueous carbonate-containing solution to form a precipitate, isolating the precipitate, optionally washing the isolated precipitate, and drying the isolated precipitate to give a dried precipitate,

(b) mixing the dry precipitate obtained in step (a) with an aluminum-containing binder selected from the group consisting of boehmite and pseudoboehmite,

(c) extruding the mixture obtained in step (b), to give an extrudate, and

(d) calcining the extrudate obtained in step (c), at a temperature in the range from 300 to 750°C, preferably in the range from 600°C to 750°C, more particularly at about 750°C, to give an extruded shaped body.

The invention further relates to the use of Cu-Al-Mn catalysts of the invention for hydrogenating organic compounds, more particularly compounds which contain a carbonyl function.

#### **Detailed description of the invention**

The extruded shaped catalyst bodies of the invention comprise copper in an amount in the range of 20 - 43 wt%, preferably in the range of 25 - 42 wt%, more preferably in the range of 30 - 35 wt%, based on the

total weight of the shaped catalyst body in extruded form. The copper here is essentially in the form of copper oxide ( $\text{CuO}$ ), copper-aluminum spinel (such as  $\text{CuAl}_2\text{O}_4$ ), copper-manganese spinel (such as  $\text{CuMn}_2\text{O}_4$  or  $\text{Cu}_{1.5}\text{Mn}_{1.5}\text{O}_4$ ), elemental copper ( $\text{Cu}$ ) and/or mixtures thereof.

The extruded shaped catalyst bodies of the invention comprise aluminum in an amount in the range of 20 - 40 wt%, preferably in the range of 25 - 34 wt%, based on the total weight of the shaped catalyst bodies in extruded form. The aluminum here is present essentially in the form of aluminum oxide ( $\text{Al}_2\text{O}_3$ ), copper-aluminum spinel (such as  $\text{CuAl}_2\text{O}_4$ ) and/or mixtures thereof.

The extruded shaped catalyst bodies of the invention comprise manganese in an amount in the range of 1 - 10 wt%, preferably in the range of 2 - 8 wt%, more preferably in the range of 3 - 6 wt%, based on the total weight of the shaped catalyst bodies in extruded form. The manganese here is essentially in the form of manganese oxide ( $\text{MnO}$ ,  $\text{Mn}_2\text{O}_3$ ,  $\text{Mn}_3\text{O}_4$ ,  $\text{MnO}_2$ ,  $\text{Mn}_2\text{O}_7$ ), copper-manganese spinel (such as  $\text{CuMn}_2\text{O}_4$  or  $\text{Cu}_{1.5}\text{Mn}_{1.5}\text{O}_4$ ) and/or mixtures thereof.

With particular preference the extruded shaped catalyst bodies of the invention comprise copper in an amount in the range of 25 - 42 wt%, more particularly in the range of 30 - 35 wt%, aluminum in an amount in the range of 25 - 34 wt%, and manganese in an amount in the range of 2 - 8 wt%, more particularly in the range of 3 - 6 wt%, based on the total weight of the shaped catalyst bodies in extruded form.

The shaped catalyst body of the invention has a pore volume in the range from 250 to 700  $\text{mm}^3/\text{g}$ , preferably in the range from 400 to 650  $\text{mm}^3/\text{g}$ , more preferably in the range from 450 to 600  $\text{mm}^3/\text{g}$ , determined by mercury intrusion to DIN 66133.

In one particularly preferred embodiment, the extruded shaped catalyst bodies of the invention comprise copper in an amount in the range of 25 - 42 wt%, more particularly in the range of 30 - 35 wt%, aluminum in an amount in the range of 25 - 34 wt%, and manganese in an amount in the range of 2 - 8 wt%, more particularly in the range of 3 - 6 wt%, based on the total weight of the shaped catalyst bodies in extruded form, and have a pore volume in the range from 400 to 650 mm<sup>3</sup>/g, more preferably in the range from 450 to 600 mm<sup>3</sup>/g, determined by mercury intrusion to DIN 66133.

The term "shaped catalyst body" in the present invention is used interchangeably with the term "catalyst", particularly when the topic is the function as such.

In one preferred embodiment the shaped catalyst body has a monomodal pore radius distribution, with 50% or more, preferably 70% or more, more preferably 80% or more of the pore volume being formed by pores having a pore radius in the range from 7 to 40 nm, the pore radius distribution and the pore volume being determined by mercury intrusion to DIN 66133.

The shaped catalyst bodies preferably have a bulk density in the range from 300 to 800 g/L, preferably in the range from 400 to 700 g/L, and more preferably in the range from 450 to 650 g/L, determined to DIN ISO 903.

In another embodiment the extruded shaped catalyst bodies of the invention comprise at least one further metal different from copper, aluminum, and manganese. This at least one further metal is preferably selected from the group consisting of alkali metal, alkaline earth metal, rare earths, Fe, Ni, Cr, Co, Zn, Zr, W, Mo, and mixtures thereof, more particularly selected

from Na, Mg, Ce, Co, Zn, Zr, and mixtures thereof. The at least one further metal may be included in the form of a metal oxide of the aforementioned metals in the shaped catalyst body of the invention. The metal oxide  
5 may comprise one or more oxides of the aforementioned metals. In the shaped catalyst body the at least one further metal is present in an amount in the range of 0.1 - 12 wt%, preferably in the range of 1 - 7 wt%, more preferably in the range of 3 - 5 wt%, based on the  
10 total weight of the shaped catalyst bodies in extruded form. More preferably the shaped catalyst bodies comprise at least one further metal selected from the group consisting of Na, Mg, Ce, Co, Zn, Zr, and mixtures thereof in an amount in the range of 3 -  
15 5 wt%, based on the total weight of the shaped catalyst bodies in extruded form.

The further metal may be present in the metal oxide in various stoichiometric compositions with the oxygen  
20 and/or in one or more different oxidation states. For example, Fe may be present as iron oxide, such as FeO, Fe<sub>2</sub>O<sub>3</sub>, Fe<sub>3</sub>O<sub>4</sub>, Fe<sub>2</sub>O or mixtures thereof, Ni as nickel oxide, such as NiO, Ni<sub>2</sub>O<sub>3</sub>, NiO<sub>2</sub>, Ni<sub>3</sub>O<sub>4</sub>, or mixtures thereof, Cr as chromium oxide, such as Cr<sub>2</sub>O<sub>3</sub>, Cu  
25 chromate, such as CuCrO<sub>4</sub> or CuCr<sub>2</sub>O<sub>7</sub>, Cu chromite, such as CuCr<sub>2</sub>O<sub>4</sub> or mixtures thereof, Co as cobalt oxide, such as CoO, Co<sub>2</sub>O<sub>3</sub> or Co<sub>3</sub>O<sub>4</sub>, Zn as zinc oxide, such as ZnO, and Zr as zirconium oxide, such as ZrO<sub>2</sub>.

30 In one preferred embodiment the Cu-, Al-, and Mn-containing shaped catalyst body of the invention in reduced form has a Cu metal surface, based on the amount of Cu present in the shaped catalyst bodies, in the range from 20 m<sup>2</sup>/g<sub>Cu</sub> to 60 m<sup>2</sup>/g<sub>Cu</sub>, preferably in the  
35 range from 25 m<sup>2</sup>/g<sub>Cu</sub> to 50 m<sup>2</sup>/g<sub>Cu</sub>, more preferably in the range from 30 m<sup>2</sup>/g<sub>Cu</sub> to 45 m<sup>2</sup>/g<sub>Cu</sub>. The Cu metal surface of the shaped catalyst bodies is determined via the principle of N<sub>2</sub>O pulse chemisorption, as described for example in G.C. Chinchén, C.M. Hay, H.D. Vandervell,

K.C. Waugh, "The measurement of copper surface areas by reactive frontal chromatography", Journal of Catalysis, volume 103, issue 1, January 1987, pages 79 - 86. The Cu metal surface is given by the amount of N<sub>2</sub> formed, which can be determined by way of a thermal conductivity detector.

The shaped catalyst bodies of the invention preferably possess a side crushing strength, measured according to DIN EN 1094-5, based on the length of the shaped catalyst bodies in extruded form, in the range from 5 to 40 N/mm, preferably in the range from 10 to 30 N/mm. The shaped catalyst bodies of the invention in extruded form customarily have a length in the range from 2 to 12 mm, preferably in the range from 3 to 10 mm, more particularly 4 to 7 mm. The lengths of the shaped catalyst bodies in extruded form can be determined, for example, by a commercial apparatus, such as a Retsch Camsizer®, for example. The side crushing strength and the length are typically determined for a multiplicity of shaped catalyst bodies (e.g., from 30 to 200, preferably 50 to 120, for example 100 shaped catalyst bodies). From the values obtained for the side crushing strength (in N) the arithmetic mean is formed. The side crushing strength relative to the length of the shaped catalyst bodies (in N/mm) is given by standardizing the arithmetic mean of the side crushing strength to the arithmetically averaged length of the shaped catalyst bodies in extruded form.

The extrudates preferably have a diameter in the range from 0.5 to 10 mm, more preferably in the range from 1 to 6 mm, and very preferably in the range from 1.5 to 3.5 mm. The diameter of the shaped catalyst bodies can be analyzed using a Retsch Camsizer®, for example.

In one particularly preferred embodiment the shaped catalyst bodies in extruded form have grooves in longitudinal direction having a depth in the range from

0.3 mm to 0.9 mm, preferably of about 0.7 mm, and a width in the range from 1.0 to 1.5 mm, preferably of about 1.2 mm.

- 5 The invention further relates to a process for producing Cu-, Al-, and Mn-containing shaped catalyst bodies in extruded form.

10 In the process of the invention for producing an extruded shaped catalyst body, first of all at least one aqueous solution of copper compounds, aluminum compounds, manganese compounds, and optionally further metal compounds, and at least one aqueous, carbonate-containing solution, are provided.

15 The wording "aqueous solution of copper compounds, aluminum compounds, manganese compounds, and optionally further metal compounds" in the sense of the present invention includes not only aqueous solutions but also  
20 aqueous suspensions and aqueous slurries of the copper compounds, aluminum compounds, manganese compounds, and optionally further metal compounds, preference being given to aqueous solutions. The at least one aqueous solution of copper compounds, aluminum compounds,  
25 manganese compounds, and optionally further metal compounds is prepared, for example, by dissolving, suspending and/or slurring, preferably by dissolving, at least one copper compound, at least one aluminum compound, at least one manganese compound, and  
30 optionally one or more further metal compounds, in water, at acidic, neutral or basic pH, preferably at acidic or neutral pH.

35 Copper compounds, aluminum compounds, and manganese compounds that can be used are in principle all compounds of copper, aluminum, and manganese that are highly soluble in water, acids or alkalis, more particularly the salts of the stated metals, especially their nitrates, carbonates, oxides, hydroxides,

hydroxocarbonates, their halides, such as chlorides, bromides, and/or iodides, and/or their sulfates. If oxides of the metals, such as copper oxide and/or aluminum oxide and/or manganese oxide, are used for preparing the aqueous solutions, then they are preferably dissolved completely or partly by addition of a suitable mineral acid. The copper in copper oxide may be present in one oxidation state or in a plurality of different oxidation states, such as copper(I) oxide, copper(II) oxide or mixtures thereof. The mineral acid is preferably selected from  $\text{HNO}_3$ ,  $\text{HCl}$ ,  $\text{H}_2\text{SO}_4$ , and mixtures thereof.

Preferred copper compounds are copper oxide ( $\text{Cu}_2\text{O}$  and/or  $\text{CuO}$ ), copper nitrate, copper chloride, copper carbonate, copper hydroxocarbonate ( $\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$  and/or  $(\text{CuCO}_3)_2 \cdot \text{Cu}(\text{OH})_2$ ), copper acetate, and copper sulfate, especially copper nitrate.

Preferred aluminum compounds are aluminum nitrate, aluminum hydroxide, aluminum oxide hydrate (boehmite), aluminum chloride, alkali metal aluminates, and aluminum oxide ( $\text{Al}_2\text{O}_3$ ), especially aluminum nitrate and Na aluminate.

Preferred manganese compounds are manganese nitrate, manganese hydroxide, manganese oxide, manganese chloride ( $\text{MnCl}_2$ ), and manganese sulfate, manganese carbonate, more particularly manganese nitrate and manganese carbonate.

The further metal compounds are preferably selected from alkali metal compounds, alkaline earth metal compounds, rare earth metal compounds, and transition metal compounds (other than copper and manganese compounds). Particularly preferred alkali metal compounds are compounds of lithium, sodium, potassium, rubidium, and mixtures thereof, especially compounds of sodium. Particularly preferred alkaline earth metal

compounds are compounds of manganese, calcium, strontium, barium, and mixtures thereof, especially compounds of calcium, barium, and mixtures thereof. Particularly preferred rare earth metal compounds are  
5 compounds of scandium, lanthanum, cerium, yttrium, neodymium, and mixtures thereof, especially compounds of cerium. Particularly preferred transition metal compounds (other than copper compounds and manganese compounds) are compounds of zinc, silicon, titanium,  
10 nickel, chromium, iron, cobalt, molybdenum, zirconium, and mixtures thereof, especially compounds of zinc, cobalt, zirconium, and mixtures thereof. The further metal compounds used are preferably compounds of the stated metals that are highly soluble in water, acids  
15 or alkalis. More particularly the salts of the metals are used. Particularly preferred are their nitrates, such as zinc, cerium and/or zirconium nitrate, their halides, such as zinc, cerium and/or zirconium chloride, bromide and/or iodide, their oxides, such as  
20 zinc, cerium and/or zirconium oxides, and/or their sulfates, such as zinc, cerium and/or zirconium sulfate. More strongly preferred are the further metal compounds selected from the group consisting of cerium nitrate, zinc chloride, zirconium chloride, and  
25 mixtures thereof. When using oxides of the stated further metals, the metals in the oxides may be present in one or in a plurality of different oxidation states. If the metals and/or their oxides, such as zinc, cerium and/or zirconium oxide, are used for preparing the  
30 aqueous solutions of further metal compounds, then they are preferably dissolved fully or partially by addition of a suitable mineral acid.

The at least one aqueous solution of copper compounds,  
35 aluminum compounds, manganese compounds, and optionally further metal compounds may be provided in the form of two or more separate aqueous solutions of copper compounds, aluminum compounds, manganese compounds, and optionally further metal compounds. For example, one or

more aqueous solutions of copper compounds, one or more aqueous solutions of aluminum compounds, one or more aqueous solutions of manganese compounds, and optionally one or more aqueous solutions of further metal compounds may be provided. Alternatively to this, one or more joint aqueous solutions may also be provided. These solutions may be prepared by dissolving copper compounds and/or aluminum compounds and/or manganese compounds and/or optionally further metal compounds in a joint container. Also possible is the combining of aforementioned separate solutions to form a joint solution.

The aqueous, carbonate-containing solution is prepared preferably by dissolving at least one alkali metal carbonate (such as lithium, sodium, potassium, rubidium or cesium carbonate), alkaline earth metal carbonate (such as magnesium, calcium, strontium or barium carbonate) or ammonium carbonate, or mixtures thereof, in water. It is possible, simultaneously with or instead of the carbonates, to use the corresponding hydrogencarbonates, or any desired mixtures of carbonates and hydrogencarbonates.

Preference is given to using alkali metal carbonates, ammonium carbonates, alkali metal hydrogencarbonates, ammonium hydrogencarbonates or mixtures thereof, more preferably alkali metal carbonates and/or alkali metal hydrogencarbonates.

Preferred alkali metal carbonates are sodium and potassium carbonate, especially sodium carbonate. Preferred alkali metal hydrogencarbonates are sodium and potassium hydrogencarbonates, especially sodium hydrogencarbonate. Particular preference is given to using sodium carbonate and/or sodium hydrogencarbonate.

By combining the at least one aqueous solution of copper compounds, aluminum compounds, manganese

compounds, and optionally further metal compounds with the at least one aqueous, carbonate-containing solution, a precipitate is formed. The precipitate is isolated, optionally washed and/or dried, and subsequently mixed with an aluminum-containing binder before being converted into an extruded shaped body.

In one embodiment, the combining in step (a) may take place by the at least one aqueous solution of copper compounds, aluminum compounds, manganese compounds, and optionally further metal compounds (either in separate solutions and/or in one or more joint solutions and/or as a solution mixture) and the at least one aqueous, carbonate-containing solution being added simultaneously into a joint container, such as a precipitation container, for example. In that case the at least two solutions are preferably introduced continuously into the reaction volume of a precipitation mixer.

In another embodiment the combining in step (a) may also take place by metering the at least one aqueous solution of copper compounds, aluminum compounds, manganese compounds, and optionally further metal compounds (either in separate solutions and/or in one or more joint solutions and/or as a solution mixture) into the at least one aqueous, carbonate-containing solution which has been placed as an initial charge (for example, in one or more containers, such as one or more precipitation containers).

In yet a further embodiment, the combining in step (a) may also take place by metering the at least one aqueous, carbonate-containing solution into the at least one aqueous solution of copper compounds, aluminum compounds, manganese compounds, and optionally further metal compounds, that solution having been placed as an initial charge (for example, in one or

more containers, such as one or more precipitation containers).

Before being combined, the at least one aqueous  
5 solution of copper compounds, aluminum compounds,  
manganese compounds, and optionally further metal  
compounds is heated preferably to a temperature of more  
than 20°C, such as, for example, to a temperature in  
the range from 50°C to 90°C, more particularly to about  
10 80°C, during which it is preferably stirred.

Similarly, the at least one carbonate-containing  
solution, before being combined, is heated preferably  
to a temperature of more than 20°C, such as, for  
15 example, to a temperature in the range from 50°C to  
90°C, more particularly to about 80°C, and is  
preferably stirred at the same time.

In one preferred embodiment, both the at least one  
20 aqueous solution of copper compounds, aluminum  
compounds, manganese compounds, and optionally further  
metal compounds and the at least one carbonate-  
containing solution are heated to a temperature in the  
range from 50°C to 90°C, more particularly to about  
25 80°C, during which they are preferably stirred.

When the at least one aqueous solution of copper  
compounds, aluminum compounds, manganese compounds, and  
optionally further metal compounds is combined with the  
30 at least one aqueous, carbonate-containing solution, a  
precipitate is formed in the mixture (also referred to  
below as precipitate-containing solution mixture). The  
solutions are generally combined in a stirred  
container. The container is preferably stirred with an  
35 inclined blade stirrer, propeller stirrer or other  
commercially customary stirrer.

In one preferred embodiment, the solutions are combined  
in step (a) by metering volume flows of aqueous

solutions of copper compounds, aluminum compounds, manganese compounds, and optionally further metal compounds into the aqueous, carbonate-containing solution in a precipitation container. Here, the aqueous solutions of copper compounds, aluminum compounds, manganese compounds, and optionally further metal compounds may be metered as separate solutions and/or as one or more joint solutions.

The precipitate-containing solution mixture is maintained preferably at a temperature above 20°C and more particularly at a temperature in the range from 50°C to 90°C, preferably at about 80°C. In one particularly preferred embodiment of the invention the precipitate-containing solution mixture is maintained for at least 30 minutes, preferably 1 to 36 hours, more particularly about 2 hours, at a temperature in the range from 50°C to 90°C, preferably at a temperature of about 80°C, in order, where appropriate, to complete the formation of the precipitate and/or to increase the crystallinity of the precipitate by aging.

During the entire time, the pH of the mixture is maintained preferably at a level in the range from 5.0 to 8.5, more particularly in the range from 6.0 to 7.5, preferably at about 6.8.

The precipitate is isolated preferably by filtration. Alternatively to this, the precipitate may also be isolated by decanting or centrifuging. The isolated precipitate is subsequently subjected to drying. Drying may take place by means of spray drying, for example. For this purpose, a suspension having a solids content of 10 to 40 wt% is prepared from the isolated precipitate, such as a filter cake, with water. This suspension is preferably metered subsequently via a nozzle into a spray drier. The temperature in the spray drier during drying is preferably in a range from 75°C to 130°C, more particularly in a range from 90°C to

120°C. The exit temperature characteristic of the drying is preferably in the range from 90°C to 120°C and is customarily controlled by the parameters, such as amount of suspension sprayed in, solids content of the suspension (and hence the amount of water requiring evaporation), and/or temperature in the spray drier. The treatment of the material with the spray drier results in particular in a dry powder.

10 The isolated precipitate prior to drying may optionally be subjected to one or more washing steps. In that case the precipitate may first be isolated from the precipitate-containing solution mixture by using a filter press, then subjected to a flow of water in the filter press, which washes the precipitate. Alternatively, following isolation from the precipitate-containing solution mixture, the isolated precipitate may be slurried by filtration, decanting or centrifuging in a container, and then again separated from the liquid phase with the aid of a filter press, a centrifuge or a decanter. This operation is generally carried out one or more times until the filtrate attains a defined conductivity. The conductivity here generally correlates with the concentration of sodium ions.

The conductivity of the filtrate from the last washing procedure is preferably 0.5 mS/cm or less, more particularly 0.2 mS/cm or less. The conductivity is determined to DIN 38404, Part 8.

The dried precipitate obtained in step (a) described above is subsequently mixed, in a step (b), with an aluminum-containing binder.

35 In a further embodiment, step (b) encompasses steps (b1), (b2), and (b3). A part of the dried precipitate obtained in step (a) is in this case subjected to calcining in a step (b1). This calcined precipitate

obtained in step (b1) is then mixed, in a step (b2),  
with a further part of the dried (uncalcined)  
precipitate obtained in step (a), and the resulting  
mixture is thereafter mixed, in a step (b3), with an  
5 aluminum-containing binder.

The calcining in step (b1) is done by thermal  
treatment, the temperature being in the range from  
250°C to 900°C, preferably in a range from 300°C to  
10 750°C, more preferably in a range from 600°C to 750°C.  
Calcining can be performed under air, inert gas (such  
as argon or nitrogen, for example), oxygen or mixtures  
thereof. Calcining may be performed discontinuously, in  
a tray furnace, for example, or continuously, in a  
15 rotary tube furnace, for example. Calcining in the  
rotary tube furnace can be controlled through the  
residence time and different heating zones. The rotary  
tube furnace preferably has 1 to 10 different heating  
zones, more particularly around five heating zones. The  
20 temperature in the different heating zones is situated,  
for example, in the range from 300°C to 400°C for the  
first heating zone, in the range from 500°C to 600°C  
for the second heating zone, in the range from 600 to  
750°C for the third heating zone, in the range from  
25 650°C to 800°C for the fourth heating zone, and in the  
range from 500°C to 700°C for the fifth heating zone.  
The residence time in the different heating zones is  
preferably in the range from 5 min to 60 min, more  
particularly in the range from 10 min to 30 min. When a  
30 tray furnace is used, the dried precipitate obtained in  
step (a) is usually spread onto metal sheets. In the  
tray furnace, temperature profiles can be controlled by  
appropriate furnace control. The temperature profile  
may, for example, encompass heating at a heating rate  
35 of 2°C/min from 20°C to 750°C, holding at 750°C for  
3 h, and cooling at a cooling rate of 2°C/min to 20°C.

In step (b2), the calcined precipitate obtained by the  
calcining in step (b1) is mixed with dried uncalcined

precipitate obtained in step (a), in a weight ratio of uncalcined precipitate to calcined precipitate in the range from 2:98 to 98:2, preferably in the range from 10:90 to 90:10, more preferably in the range from 15:85 to 85:15, and very preferably in the range from 20:80 to 50:50. The resulting mixture of uncalcined and calcined precipitate is thereafter mixed with an aluminum-containing binder in a step (b3).

For the catalyst of the invention, preference is given to using an aluminum oxide-based, aluminum-containing binder. The aluminum oxide-based, aluminum-containing binder is in that case selected with particular preference from the group consisting of boehmite ( $\text{AlO}(\text{OH})$ ) and pseudoboehmite (gelatinous/colloidal boehmite). Boehmite is described in particular in the 9th edition of Strunz'schen Mineralsystematik; E. Schweizerbat'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart 2001: Group 4.FE.15.

The aluminum oxide-based, aluminum-containing binder which is mixed in step (b) or (b3) with the dry precipitate obtained in step (a) or with the mixture obtained in step (b2), respectively, is peptized with an acid, this peptizing taking place prior to mixing and/or during mixing. The peptizing procedure is a key step in the generation of the pore volume. Peptizing can be carried out using not only inorganic acids such as  $\text{HNO}_3$ ,  $\text{H}_2\text{SO}_4$  or  $\text{HCl}$  but also organic acids. Using strong inorganic acids or strong organic acids, such as formic acid, leads in general to a lower pore volume. For peptizing in accordance with the present invention, preference is given to using organic acids other than formic acid, preferably acetic acid or citric acid. The acid is used in an amount in the range of 0.5 and 0.01 wt%, based on the amount of aluminum-containing binder. In the case of dilute acids, such as 50% strength acetic acid, for example, the amount of

undiluted acid is taken as the basis for calculating the acid amount/binder ratio.

5 The boehmite and/or pseudoboehmite used is employed preferably in the form of powder. The powder preferably has a particle size  $D_{50}$  in the range from 10 to 40  $\mu\text{m}$ , preferably from 15 to 35  $\mu\text{m}$ , and more preferably from 20 to 30  $\mu\text{m}$ , determined by the laser diffraction method to DIN ISO 13320. The boehmite or pseudoboehmite used  
10 preferably has a pore volume in the range of 300 - 700  $\text{mm}^3/\text{g}$ , preferably in the range of 400 - 600  $\text{mm}^3/\text{g}$ , and more preferably in the range of 450 - 550  $\text{mm}^3/\text{g}$ . In one preferred embodiment, boehmite and/or pseudoboehmite is used in powder form with a particle  
15 size  $D_{50}$  in the range from 10 to 40  $\mu\text{m}$  and a pore volume in the range of 300 - 700  $\text{mm}^3/\text{g}$ , more preferably with a particle size  $D_{50}$  in the range from 15 to 35  $\mu\text{m}$  and a pore volume in the range of 400 - 600  $\text{mm}^3/\text{g}$ , more particularly with a particle size  $D_{50}$  in the range from  
20 20 to 30  $\mu\text{m}$  and a pore volume in the range of 450 - 550  $\text{mm}^3/\text{g}$ .

Suitable boehmite or pseudoboehmite powders are sold for example by Sasol under the name Pural or by Akzo  
25 Nobel or Nabaltec.

Mixing of the dried precipitate obtained in step (a) or of the mixture of calcined and uncalcined precipitate obtained in step (b2) with the aluminum-containing  
30 binder described above can be accomplished by methods known to the skilled person that ensure mixing. For example, mixing may take place in intensive mixers such as an Eirich mixer or else by means of plowshare mixers or Lödiger mixers. Kneading devices as well can be used  
35 for the mixing of powders.

The mixture obtained in step (b) or in step (b3) is subsequently extruded in step (c) by methods known to the skilled person to form shaped catalyst bodies, to

give an extrudate. Examples of extrudates are rods and ribbed rods.

5 Prior to extrusion, the mixture obtained in step (b) or in step (b3) is preferably admixed with a lubricant in an amount in the range from 0.1 to 5 wt%, based on the total weight of the material to be extruded. More preferably the lubricant is added in an amount in the range from 0.5 to 5 wt%, even more preferably in the  
10 range from 1 to 4 wt%, based on the total weight of the material to be extruded. The lubricant is preferably graphite, oil or fatty acid salt, preferably graphite or steatite oil.

15 The extrudate obtained in step (c) is optionally dried in step (c1). The extrudate can be dried by heating to a temperature in the range from 75°C to 130°C, in a furnace, for example, such as a tray furnace.

20 Thereafter the extrudate obtained in step (c) or the dried extrudate obtained in step (c1) is calcined in step (d) at a temperature in the range from 300°C to 750°C, preferably in the range from 600°C to 750°C, more particularly at about 750°C, to give an extruded  
25 shaped body.

In a further embodiment, the extruded shaped catalyst body obtained in step (d) is reduced in a step (e).

30 Reducing takes place preferably by heating of the extruded shaped catalyst body in a reducing atmosphere. The reducing atmosphere more particularly is hydrogen. Reducing takes place for example at a temperature in the range from 150°C to 450°C, more particularly in the  
35 range from 180°C to 250°C, preferably in the range from 190°C to 210°C, more preferably at about 200°C. Reducing takes place for example over a period of 1 hour to 10 days, more particularly over a period of 2 hours to 72 hours, preferably over a period of 24 to

48 hours. In one preferred embodiment the reducing takes place at a temperature in the range from 190°C to 210°C over a period of 24 to 48 hours.

5 Following reduction, the shaped catalyst bodies are preferably stabilized wet or dry. In the case of wet stabilization, the shaped bodies are covered with liquid in order to prevent as far as possible contact with oxygen. Suitable liquids include organic liquids  
10 and water, preferably organic liquids. Preferred organic liquids are those having a vapor pressure at 20°C at 0.5 hPa or less. Examples of suitable organic liquids are isodecanol, Nafol, fatty alcohols, hexadecane, 2-ethylhexanol, propylene glycol, and  
15 mixtures thereof, especially isodecanol.

In the case of dry stabilization, a mixture of oxygen or an oxygen-containing gas, preferably air, and an inert gas, such as argon or nitrogen, is metered into  
20 the reduction reactor. The concentration of oxygen in the mixture is raised preferably from about 0.04 vol% to about 21 vol%. For example, a mixture of air and inert gas can be metered in, with the ratio of air to inert gas at the start being about 0.2 vol% air to  
25 99.8 vol% inert gas. The ratio of air to inert gas is then gradually increased (e.g., continuously or in steps) until, ultimately, for example, 100 vol% air is metered in (corresponding to an oxygen concentration of around 21 vol%). Without being tied to any theory, it  
30 is supposed that the metered addition of air or oxygen forms a thin oxide layer having a thickness of, for example, 0.5 to 50 nm, preferably 1 to 20 nm, more particularly 1 to 10 nm, on the surface of the catalyst, thereby protecting the shaped catalyst body  
35 from further oxidation. In the case of the dry stabilization, the reactor temperature is preferably 100°C or less, more preferably 20°C to 70°C, and very preferably 30°C to 50°C. After this stabilization, the shaped catalyst body is "transportable" and can be

transported to the user/plant operator. Where the catalyst user performs step (e) in situ in the reactor, stabilization is customarily omitted.

- 5 The shaped catalyst bodies of the invention are suitable for use in numerous reactions. Possible reactions include synthesis gas reactions, methanol syntheses, Fischer-Tropsch synthesis, pyridine syntheses, ester hydrogenolyses, amination reactions,
- 10 N-alkylations, hydrogenations of nitriles to amines, hydrogenation of acrylonitrile, hydrogenation of fatty acid esters, hydrogenation of diesters to diols (especially maleic esters), hydrogenation of sugars to polyols, alkylation of a phenol with alcohol, amination
- 15 of an alcohol, dehydrogenation of an alcohol, hydrogenation of an aldehyde, hydrogenation of an amide, hydrogenation of a fatty acid, by esterification and subsequent hydrogenolysis, for example; selective hydrogenation of a fat, selective hydrogenation of an
- 20 oil, hydrogenation of a nitrile, hydrogenation of a nitroaromatic hydrocarbon, hydrogenation of a ketone, hydrogenation of furfural, hydrogenation of an ester, and hydrogenation of carbon monoxide to methanol.
- 25 In a preferred embodiment, the catalysts produced by the process of the invention are used in the hydrogenation of carbonyl compounds, more particularly for the hydrogenation of aldehydes, ketones, carboxylic acids and/or their esters or dicarboxylic acids and/or
- 30 their diesters, very preferably for the hydrogenation of fatty acid esters, more particularly fatty acid alkyl esters, preferably fatty acid methyl esters, or maleic esters.
- 35 The shaped catalyst body of the invention is especially suitable for the liquid-phase hydrogenation of carboxylic acids, preferably of fatty acids and/or fatty acid mixtures having 5 to 24 C atoms and/or esters thereof, optionally in a mixture with alcohols,

to give the corresponding fatty alcohols. In this case the fatty acids or fatty acid mixtures may be esterified in situ with alcohols present in the reaction mixture. Preferred alcohols present in the  
5 reaction mixture are fatty alcohols or mixtures of fatty alcohols having 5 to 24 C atoms. Particularly preferred is the use of the above-described catalyst for the hydrogenation of fatty acid methyl ester.

## 10 **Determination of physical parameters**

The physical parameters described in the present specification are determined as follows unless  
15 otherwise stated:

Conductivity is determined to DIN 38404, Part 8.

Particle size  $D_{50}$  is determined by the laser diffraction method to DIN ISO 13320.

20 Residual loss on ignition is determined to DIN EN 196-2.

Pore volume and pore radius distribution are determined  
25 by mercury intrusion to DIN 66133.

Cu metal surface area is determined using  $N_2O$  pulse chemisorption.

30 Side crushing strength is determined in accordance with DIN EN 1094-5. The side crushing strength is obtained customarily from the arithmetic mean of 100 measurements.

35 The length distribution of the shaped catalyst bodies is determined using a Camsizer® from Retsch GmbH, Germany. The length reported for the shaped catalyst bodies is customarily the arithmetic mean of the lengths measured.

## **Examples**

The invention is elucidated in more detail by means of the following, nonlimiting examples. Although these examples describe specific embodiments of the invention, they serve only to illustrate the invention and are not to be interpreted as restricting the invention in any way whatsoever. As the skilled person is aware, numerous modifications may be made to the embodiments without deviating from the scope of protection of the invention as it is defined by the appended claims.

### **Reference example 1 (production of the uncalcined material)**

The uncalcined material is produced via precipitation of the metal nitrates with sodium carbonate to give their carbonates, after which the precipitate is filtered off, washed, and spray-dried.

Solution 1 is prepared from 1250 g of  $\text{Cu}(\text{NO}_3)_2 \times 3 \text{ H}_2\text{O}$ , 220 g of  $\text{Mn}(\text{NO}_3)_2 \times 4 \text{ H}_2\text{O}$ , 1800 g of  $\text{Al}(\text{NO}_3)_3 \times 9 \text{ H}_2\text{O}$ , and 9 L of  $\text{H}_2\text{O}$ . Solution 2 is prepared from 1720 g of  $\text{Na}_2\text{CO}_3$  and 7.5 L of  $\text{H}_2\text{O}$ . The two solutions are heated to 80°C, being stirred in the process. They are then metered into a precipitation container. The pH in the precipitation container is 6.8. The volume flow rates of solutions 1 and 2 are set such that this pH is established. As soon as the two solutions have been consumed, the precipitate formed is filtered off and washed with water. The filter cake is then resuspended in about 2 L of water and spray-dried. The resulting dried but as yet uncalcined material in powder form is the starting material for the further preparations.

### **Reference example 2 (production of the calcined material)**

Calcined material is produced by calcining uncalcined material (produced as described in reference example 1) in a forced air oven at 730°C for 3 hours. The residual loss on ignition at 1000°C (LOI) is about 5%.

5

**Example 1 (production of shaped catalyst body 1)**

For producing catalyst 1, 17 g of Pural SCF 55 are peptized with 34 g of 2.5% strength acetic acid and then mixed with 320 g of uncalcined material (produced  
10 as described in reference example 1) and 165 g of deionized water in a double-Z kneader. The mixture is admixed with 10 g of steatite oil as lubricant. Thereafter the mixture is extruded to rods having a diameter of 3.2 mm and a length in the range from 3 to  
15 10 mm. The extrudates are dried at 120°C for 16 hours and then calcined at 750°C for 3 hours.

**Example 2 (production of shaped catalyst body 2)**

For producing catalyst 2, 125 g of Pural SCF 55 are  
20 peptized with 250 g of 2.5% strength acetic acid and then mixed with 720 g of uncalcined material (produced as described in reference example 1) and 370 g of deionized water in a double-Z kneader. The mixture is admixed with 20 g of steatite oil as lubricant.  
25 Thereafter the mixture is extruded to rods having a diameter of 3.2 mm and a length in the range from 3 to 10 mm. The extrudates are dried at 120°C for 16 hours and then calcined at 750°C for 3 hours.

30 **Example 3 (production of shaped catalyst body 3)**

For producing catalyst 3, 600 g of Pural SCF 55 are  
peptized with 1200 g of 2.5% strength acetic acid and then mixed with 1950 g of uncalcined material (produced  
as described in reference example 1) and 1000 g of  
35 deionized water in a double-Z kneader. The mixture is admixed with 80 g of steatite oil as lubricant. Thereafter the mixture is extruded to rods having a diameter of 3.2 mm and a length in the range from 3 to

10 mm. The extrudates are dried at 120°C for 16 hours and then calcined at 750°C for 3 hours.

**Example 4 (production of shaped catalyst body 4)**

5 For producing catalyst 4, 173 g of Pural SCF 55 are  
peptized with 346 g of 2.5% strength acetic acid and  
then mixed with 320 g of uncalcined material (produced  
as described in reference example 1) and 165 g of  
10 deionized water in a double-Z kneader. The mixture is  
admixed with 15 g of steatite oil as lubricant.  
Thereafter the mixture is extruded to rods having a  
diameter of 3.2 mm and a length in the range from 3 to  
10 mm. The extrudates are dried at 120°C for 16 hours  
and then calcined at 750°C for 3 hours.

15

**Example 5 (production of shaped catalyst body 5)**

For producing catalyst 5, 262 g of Pural SCF 55 are  
peptized with 520 g of 2.5% strength acetic acid and  
then mixed with 320 g of uncalcined material (produced  
20 as described in reference example 1) and 165 g of  
deionized water in a double-Z kneader. The mixture is  
admixed with 17.5 g of steatite oil as lubricant.  
Thereafter the mixture is extruded to rods having a  
diameter of 3.2 mm and a length in the range from 3 to  
25 10 mm. The extrudates are dried at 120°C for 16 hours  
and then calcined at 750°C for 3 hours.

**Example 6 (production of shaped catalyst body 6)**

Shaped catalyst body 6 is produced as for shaped  
30 catalyst body 3 (as described in example 3), with the  
difference that a die for grooved extrudates is used  
for the extrusion (diameter approximately 3.2 mm).  
Drying and calcining took place likewise in analogy to  
the procedures described in example 3. The finished  
35 extrudates have three grooves in the longitudinal  
direction, with a depth of about 0.7 mm and a width of  
about 1.2 mm.

**Example 7 (production of shaped catalyst body 7)**

For the production of catalyst 7, 600 g of Pural SCF 55 are mixed with 1950 g of uncalcined material (produced as described in reference example 1) in a double-Z kneader. Then first 1200 g of 2.5% strength acetic acid and, immediately thereafter, 1000 g of deionized water are added and the resulting mixture is kneaded for 60 minutes. After kneading has been carried out, 80 g of steatite oil as lubricant are admixed to the mixture and the mixture is subsequently extruded (diameter 3.2 mm). The extrudates are dried at 120°C for 16 hours and then calcined at 750°C for 3 hours.

**Comparative example 1 (production of reference catalyst A)**

For the production of reference catalyst A, 100 g of calcined material (produced as described in reference example 2) and 3 g of graphite are mixed and tableted to form shaped bodies having a diameter of around 3 mm and a height of around 3 mm.

**Comparative example 2 (production of reference catalyst B)**

For the production of reference catalyst B, 150 g of Volclay SPV are mixed with 450 g of uncalcined material (produced as described in reference example 1) and 50 g of deionized water. The mixture is subsequently extruded (diameter 3.2 mm). The extrudates are dried at 120°C for 16 hours and then calcined at 750°C for 3 hours.

**Comparative example 3 (production of reference catalyst C)**

For the production of reference catalyst C, 375 g of Ludox AS40 are mixed with 450 g of uncalcined material (produced as described in reference example 1), 10 g of Zusoplast C-92 (compression and lubricity aid), and 250 g of deionized water. The mixture is subsequently extruded (diameter 3.2 mm). The extrudates are dried at

120°C for 16 hours and then calcined at 750°C for 3 hours.

### Determination of pore volume

5

The pore volume is determined by mercury intrusion to DIN 66133. Table 1 shows the pore volume of the inventive catalysts and reference catalysts:

10 **Table 1:** pore volume of the inventive shaped catalyst bodies and reference catalysts

|                    | Pore<br>Volume<br>[mm <sup>3</sup> /g] | Relative pore volume [mm <sup>3</sup> /g] |           |         |          |
|--------------------|----------------------------------------|-------------------------------------------|-----------|---------|----------|
|                    |                                        | Pore radius ranges                        |           |         |          |
|                    |                                        | 7500-875 nm                               | 875-40 nm | 40-7 nm | 7-3.7 nm |
| <b>Cat. 1</b>      | 290                                    | 5.8                                       | 7.2       | 267.1   | 9.9      |
| <b>Cat. 2</b>      | 463                                    | 1.9                                       | 13        | 432.9   | 15.3     |
| <b>Cat. 3</b>      | 497                                    | 2.5                                       | 10.4      | 463.7   | 20.4     |
| <b>Cat. 4</b>      | 520                                    | 5.2                                       | 12.5      | 476.1   | 26.2     |
| <b>Cat. 5</b>      | 550                                    | 2.9                                       | 11.1      | 508.9   | 27.1     |
| <b>Cat. 6</b>      | 515                                    | 5.5                                       | 12.4      | 471.8   | 25.3     |
| <b>Cat. 7</b>      | 451                                    | 0.4                                       | 23.1      | 393.2   | 34.5     |
| <b>Ref. cat. A</b> | 150                                    | 0                                         | 0         | 136.9   | 13.1     |
| <b>Ref. cat. B</b> | 336                                    | 0                                         | 0         | 118     | 218      |
| <b>Ref. cat. B</b> | 463                                    | 2.7                                       | 45.3      | 379     | 35.7     |

### Chemical analysis

15

For chemical analysis of the catalysts, they are first brought into solution with a fused potassium disulfate melt, and then the chemical composition is determined by the method of ICP (inductively coupled plasma).  
 20 Table 2 shows the chemical compositions of the various catalysts. The values are reported without loss of ignition. The loss of ignition was determined according to DIN ISO 803/806.

25 **Table 2:** chemical composition of the various catalysts

|                    | Cu [wt%] | Mn [wt%] | Al [wt%] | Si [wt%] | LOI<br>(1000°C)<br>[wt%] |
|--------------------|----------|----------|----------|----------|--------------------------|
| <b>Cat. 1</b>      | 41.9     | 6.6      | 20.4     | ---      | 3.6                      |
| <b>Cat. 2</b>      | 37.5     | 5.9      | 24.6     | ---      | 3.6                      |
| <b>Cat. 3</b>      | 34.3     | 5.4      | 27.3     | ---      | 3.7                      |
| <b>Cat. 4</b>      | 28.7     | 4.5      | 33.1     | ---      | 3.7                      |
| <b>Cat. 5</b>      | 24.3     | 3.8      | 37.3     | ---      | 3.6                      |
| <b>Cat. 6</b>      | 34.8     | 5.3      | 27.1     | ---      | 3.5                      |
| <b>Cat. 7</b>      | 34.2     | 5.5      | 27.5     | ---      | 3.8                      |
| <b>Ref. cat. A</b> | 45.0     | 6.5      | 18.0     | ---      | 7.0                      |
| <b>Ref. cat. B</b> | 32.4     | 4.9      | 15.9     | 8.6      | 1.9                      |
| <b>Ref. cat. B</b> | 31.0     | 4.7      | 12.4     | 15.3     | 5.0                      |

#### **Determination of particle size distribution (binder materials)**

5

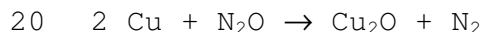
The particle sizes are determined by the laser diffraction method to DIN ISO 13320 using a Malvern Mastersizer 2000 in accordance with the manufacturer's instructions, the sample being homogenized in deionized water prior to measurement, without any auxiliaries added, and treated with ultrasound for 5 minutes. The D values reported are based on the sample volume.

10

#### **Determination of Cu metal surface area**

15

The Cu metal surface area of the catalysts is determined via the principle of N<sub>2</sub>O decomposition (N<sub>2</sub>O pulse chemisorption):



This is done by reducing the sample with hydrogen in a TRACE GC ULTRA reduction furnace (from Brechbühler) at 240°C for 16 hours (forming gas 5% H<sub>2</sub> in He). The sample is then transferred to the TPDRO 1100 Series instrument

25

from Thermo Electron and flushed with He, and the N<sub>2</sub>O pulse chemisorption is commenced. The CU metal surface area is given by the amount of N<sub>2</sub> formed in He, which is determined via a thermal conductivity detector.

5

**Table 3:** Cu metal surface areas of the inventive catalysts and reference catalysts

|                    | Cu metal surface<br>area per g of sample | Cu metal surface<br>area per g of Cu |
|--------------------|------------------------------------------|--------------------------------------|
|                    | [m <sup>2</sup> /g <sub>sample</sub> ]   | [m <sup>2</sup> /g <sub>Cu</sub> ]   |
| <b>Cat. 1</b>      | 9.1                                      | 21.7                                 |
| <b>Cat. 2</b>      | 11.3                                     | 30.1                                 |
| <b>Cat. 3</b>      | 12.6                                     | 36.7                                 |
| <b>Cat. 4</b>      | 15.0                                     | 52.3                                 |
| <b>Cat. 5</b>      | 20.0                                     | 82.4                                 |
| <b>Cat. 6</b>      | 12.5                                     | 36.4                                 |
| <b>Cat. 7</b>      | 13.2                                     | 38.6                                 |
| <b>Ref. cat. A</b> | 6.7                                      | 14.9                                 |
| <b>Ref. cat. B</b> | 8.3                                      | 25.6                                 |
| <b>Ref. cat. B</b> | 7.5                                      | 24.2                                 |

## 10 Determination of bulk density

The bulk density is determined to DIN ISO 903. Table 4 shows the bulk density of the various catalysts.

## 15 **Table 4:** bulk densities of the inventive catalysts and reference catalysts

|             | Bulk density [g/L] |
|-------------|--------------------|
| Cat. 1      | 680                |
| Cat. 2      | 585                |
| Cat. 3      | 550                |
| Cat. 4      | 530                |
| Cat. 5      | 490                |
| Cat. 6      | 530                |
| Cat. 7      | 550                |
| Ref. cat. A | 1500               |
| Ref. cat. B | 600                |
| Ref. cat. B | 550                |

#### Determination of side crushing strength

5

The side crushing strength is determined to DIN EN 1094-5. The side crushing strength is given by the arithmetic mean of 100 measurements. For the extrudates, the side crushing strength is reported based on the length of the measured extrudates in N per mm extrudate length, the length of the extrudates being the arithmetic mean of the measured lengths of around 100 shaped catalyst bodies in extruded form. In relation to the tablets, a specific value for the side crushing strength can be reported, by virtue of the consistent dimensions.

10

15

**Table 5:** side crushing strengths of the inventive catalysts and reference catalysts

20

|                    | <b>Side crushing strength</b> |
|--------------------|-------------------------------|
| <b>Cat. 1</b>      | 4.5 N/mm                      |
| <b>Cat. 2</b>      | 11.6 N/mm                     |
| <b>Cat. 3</b>      | 13.8 N/mm                     |
| <b>Cat. 4</b>      | 15.1 N/mm                     |
| <b>Cat. 5</b>      | 18.2 N/mm                     |
| <b>Cat. 6</b>      | 10.5 N/mm                     |
| <b>Cat. 7</b>      | 15.3 N/mm                     |
| <b>Ref. cat. A</b> | 85.0 N                        |
| <b>Ref. cat. B</b> | 56 N/mm                       |
| <b>Ref. cat. C</b> | 22 N/mm                       |

### **Example 8 (activity measurements)**

The activity of the catalysts is investigated in  
 5 relation to the hydrogenation of fatty acid methyl  
 ester (FAME). This is done using an electrically heated  
 fixed-bed reactor having a reactor volume of 25 ml. The  
 test is carried out using lauric acid methyl ester (C12  
 methyl ester). For evaluation of the ester conversion  
 10 and of the selectivity with respect to the fatty  
 alcohol and with respect to the formation of  
 byproducts, respectively, the reaction product formed  
 is analyzed by gas chromatography. The conversion is  
 calculated from the amount-of-substance of ester used  
 15 and from the remaining amount-of-substance of ester in  
 the product.

For the analysis by gas chromatography, 6.0000 g of the  
 product formed are mixed with 0.2000 g of 5-nonanol  
 20 (internal standard). The sample is subsequently  
 analyzed twice using a gas chromatograph.

Equipment used:

GC: Agilent 7890A with FID

25 Column: ZB-1, 60 m × 0.25 mm from Phenomenex

Software: EZ Chrom Elite Version 3.3.2 SP1

Test conditions in the hydrogenation of lauric acid methyl ester:

Reaction temperature: 160°C, 180°C, 240°C

Pressure: 280 bar

5 GHSV (H<sub>2</sub>): 20 000 h<sup>-1</sup>

LHSV (ester): 1.4 h<sup>-1</sup>

In table 1, the results for the catalysts described are reported as values for the conversions of C12 methyl ester at 180°C. Clearly apparent are the improved activity and selectivity of the inventive catalysts in comparison to the comparative catalysts.

**Table 6:** conversions of C12 methyl ester and formation of paraffin byproducts at 160°C, 180°C, and 240°C

|                        | Conversion of C12 methyl ester [%] |       |       | Selectivity with respect to paraffin [%] |       |       |
|------------------------|------------------------------------|-------|-------|------------------------------------------|-------|-------|
|                        | 240°C                              | 180°C | 160°C | 240°C                                    | 180°C | 160°C |
| Shaped catalyst body 1 | 92.0                               | 70.1  | 60.0  | 1.2                                      | 0.2   | 0.0   |
| Shaped catalyst body 2 | 98.3                               | 80.3  | 61.5  | 1.1                                      | 0.0   | 0.0   |
| Shaped catalyst body 3 | 98.9                               | 84.3  | 61.0  | 1.2                                      | 0.1   | 0.0   |
| Shaped catalyst body 4 | 98.0                               | 83.8  | 61.0  | 1.2                                      | 0.1   | 0.0   |
| Shaped catalyst body 5 | 95.0                               | 75.1  | 61.0  | 1.1                                      | 0.1   | 0.0   |
| Shaped catalyst body 6 | 99.1                               | 86.0  | 63.4  | 0.8                                      | 0.0   | 0.0   |
| Shaped catalyst body 7 | 98.9                               | 84.7  | 61.2  | 1.1                                      | 0.0   | 0.0   |
| Reference catalyst A   | 97.8                               | 81.3  | 60.5  | 1.5                                      | 0.2   | 0.1   |
| Reference catalyst B   | 51.2                               | 23.2  | 12.3  | 1.8                                      | 0.3   | 0.3   |
| Reference catalyst C   | 78.9                               | 65.0  | 39.8  | 1.5                                      | 0.2   | 0.3   |

In table 6 it is evident that the shaped catalyst bodies produced in accordance with the invention are distinguished by a significantly increased conversion of lauric acid methyl ester and an increased selectivity, i.e., reduced formation of the paraffin byproduct, in comparison to the comparative catalysts.

This increase was observed at all three temperatures selected, 160°C, 180°C, and 240°C.

In summary, therefore, it can be stated that by means  
5 of the shaped catalyst body of the invention, an  
improvement in productivity is achieved, more  
particularly an increase in the conversion to the  
target product.

# **CLAIMS**

1. A shaped catalyst body in extruded form,  
5 comprising Cu in an amount in the range of 20 - 43 wt%, preferably in the range of 25 - 42 wt%, Al in an amount in the range of 20 - 40 wt%, preferably in the range of 25 - 34 wt%, and Mn in an amount in the range of 1 - 10 wt%, preferably  
10 in the range of 2 - 8 wt%, more preferably in the range of 3 - 6 wt%, based on the total weight of the shaped catalyst body in extruded form,  
  
wherein the shaped catalyst body has a pore volume  
15 in the range from 250 to 700 mm<sup>3</sup>/g, preferably in the range from 400 to 650 mm<sup>3</sup>/g, more preferably in the range from 450 to 600 mm<sup>3</sup>/g, determined by mercury intrusion to DIN 66133.
- 20 2. The shaped catalyst body as claimed in claim 1, wherein the shaped catalyst body has a monomodal pore radius distribution and wherein 50% or more, preferably 70% or more, more preferably 80% or more of the pore volume is formed by pores having  
25 a pore radius in the range from 7 to 40 nm, the pore radius distribution and the pore volume being determined by mercury intrusion to DIN 66133.
3. The shaped catalyst body as claimed in claim 1 or  
30 2, having a bulk density in the range from 300 to 800 g/L, preferably in the range from 400 to 700 g/L, and more preferably in the range from 450 to 650 g/L, determined to DIN ISO 903.
- 35 4. The shaped catalyst body as claimed in claim 1, 2 or 3, comprising at least one further metal selected from the group consisting of alkali metal, alkaline earth metal, rare earths, Fe, Ni, Cr, Co, Zn, and Zr.

5. The shaped catalyst body as claimed in any of claims 1 to 4, wherein the shaped body has a side crushing strength, based on the length of the extrudates, in the range from 5 to 40 N/mm, preferably in the range from 10 to 30 N/mm, the side crushing strength being determined to DIN EN 1094-5.
6. The shaped catalyst body as claimed in any of claims 1 to 5, wherein the shaped body has a diameter in the range from 1 to 6 mm, preferably in the range from 1.5 to 3.5 mm.
7. The shaped catalyst body as claimed in any of claims 1 to 6, wherein the shaped body has grooves in longitudinal direction having a depth in the range from 0.3 mm to 0.9 mm, preferably of about 0.7 mm, and a width in the range from 1.0 to 1.5 mm, preferably of about 1.2 mm.
8. The shaped catalyst body as claimed in any of claims 1 to 7, wherein the shaped catalyst body in reduced form has a Cu metal surface, based on the amount of Cu in the shaped catalyst body, in the range from 20 m<sup>2</sup>/gCu to 60 m<sup>2</sup>/gCu, preferably in the range from 25 m<sup>2</sup>/gCu to 50 m<sup>2</sup>/gCu, more preferably in the range from 30 m<sup>2</sup>/gCu to 45 m<sup>2</sup>/gCu, determined by N<sub>2</sub>O pulse chemisorption.
9. A process for producing an extruded shaped catalyst body, comprising the following steps:
  - (a) combining (i) at least one aqueous solution of copper compounds, aluminum compounds, manganese compounds, and optionally transition metal compounds and (ii) at least one aqueous carbonate-containing solution to form a precipitate, isolating the precipitate, optionally washing the

isolated precipitate, and drying the isolated precipitate to give a dried precipitate,

5 (b) mixing the dry precipitate obtained in step (a) with an aluminum-containing binder selected from the group consisting of boehmite and pseudoboehmite,

10 (c) extruding the mixture obtained in step (b), to give an extrudate, and

(d) calcining the extrudate obtained in step (c), at a temperature in the range from 300 to 750°C, preferably in the range from 600°C to 750°C, more  
15 particularly at about 750°C, to give an extruded shaped catalyst body.

10. The process as claimed in claim 9, wherein step (b) comprises:

20 (b1) calcining dried precipitate obtained in step (a) at a temperature in the range from 250°C to 900°C, preferably at a temperature in the range from 300°C to 750°C, more preferably in the range from 600°C to 750°C, to give a calcined  
25 precipitate,

(b2) mixing dried precipitate obtained in step (a) with calcined precipitate obtained in step (b1) in a weight ratio of dried precipitate to calcined  
30 precipitate in the range from 2:98 to 98:2, preferably in the range from 10:90 to 90:10, more preferably in the range from 15:85 to 85:15, and very preferably in the range from 20:80 to 50:50, to give a mixture, and

35 (b3) mixing the mixture obtained in step (b2) with an aluminum-containing binder selected from the group consisting of boehmite and pseudoboehmite.

11. The process as claimed in claim 9 or 10, wherein the aluminum-containing binder is peptized by addition of an acid, preferably an organic acid, the peptizing taking place preferably before or during step (b).
12. The process as claimed in claim 11, wherein the organic acid is selected from acetic acid and citric acid.
13. The process as claimed in any of claims 9 to 12, wherein the mixture obtained from step (b) or step (b3) is admixed, prior to extrusion, with a lubricant in an amount in the range from 0.1 to 5 wt%, based on the total weight of the material to be extruded.
14. The process as claimed in any of claims 9 to 13, wherein the binder has a pore volume in the range of 300 - 700 mm<sup>3</sup>/g, preferably in the range of 400 - 600 mm<sup>3</sup>/g, and more preferably in the range of 450 - 550 mm<sup>3</sup>/g, the pore volume being determined by mercury intrusion to DIN 66133.
15. The process as claimed in any of claims 9 to 14, wherein the binder has a particle size D<sub>50</sub> in the range from 10 to 40 µm, preferably in the range from 15 to 35 µm, and more preferably in the range from 20 to 30 µm, determined by the laser diffraction method to DIN ISO 13320.
16. The process as claimed in any of claims 9 to 15, comprising the following step:
- (e) reducing the extruded shaped catalyst body obtained in step (d) to give a reduced shaped catalyst body.

17. A shaped catalyst body obtainable by a process as claimed in any of claims 9 to 16.
18. The use of a shaped catalyst body as claimed in  
5 any of claims 1 to 8 and 17 for hydrogenating  
carbonyl compounds.