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(54) Process for the preparation of hydrocarbons

(57) Process for the preparation of hydrocarbons in which a mixture of carbon monoxide and hydrogen is contacted with a catalyst comprising cobalt supported on a carrier, the cobalt being distributed over the carrier in such a way as to satisfy the relation

$$\frac{\Sigma V_p}{\Sigma V_c} < 0.85,$$

wherein ΣV_c represents the total volume of the catalyst particles under consideration and ΣV_p is found by totalizing the peel volumina present in the catalyst particles, when the latter is taken to be composed of a kernel surrounded by a peel, the kernel being of such a shape that at every point of the kernel perimeter the shortest distance (d) to the perimeter of the peel is the same, and that d is equal for all catalyst particles under consideration and has been chosen such that the quantity of cobalt present in ΣV_p is 90% of the quantity of cobalt present in ΣV_c .

GB 2 164 266 A

SPECIFICATION

Process for the preparation of hydrocarbons

- 5 The invention relates to a process for the preparation of hydrocarbons by catalytic reaction of carbon monoxide with hydrogen. 5

The preparation of hydrocarbons from a H_2/CO mixture by contacting this mixture at elevated temperature and pressure with a catalyst is known in the literature as the Fischer-Tropsch hydrocarbon synthesis. Catalysts suitable for the purpose are those comprising cobalt supported on a carrier. Such catalysts can be prepared by keeping particles of a porous carrier in contact with a solution of a cobalt compound for a considerable period of time, then removing the solvent and calcining and activating the composition obtained. Thus are generally obtained catalyst particles in which the cobalt is homogeneously distributed over the carrier material, viz at every point of the catalyst particle the cobalt concentration present is virtually the same.

- 15 An investigation into the use of catalysts comprising cobalt on a carrier for preparing hydrocarbons from H_2/CO mixtures has shown that the C_5^+ selectivity of these catalysts is highly dependent on the way in which the cobalt is distributed over the carrier material. It has been found that catalysts in which the cobalt is inhomogeneously distributed over the carrier material show a much higher C_5^+ selectivity than similar catalysts where the cobalt is distributed homogeneously over the carrier, provided that said inhomogeneous distribution meets certain requirements. In order to assess the inhomogeneity of the cobalt distribution over the catalyst particles, the latter are taken to be composed of a kernel surrounded by a peel, the kernel being of such a shape that at every point of the kernel perimeter the shortest distance (d) to the perimeter of the peel is the same and that d is equal for all catalyst particles under consideration and has been chosen such that the quantity of cobalt present in the total peel volume (ΣV_p) is 90% of the quantity of cobalt present in the total volume of the catalyst particles under consideration (ΣV_c). It has been found that the catalysts having an inhomogeneous cobalt distribution show no significantly improved C_5^+ selectivity as related to catalysts with homogeneous cobalt distribution unless the inhomogeneous cobalt distribution is such as to meet the requirement

$$30 \quad \frac{\Sigma V_p}{\Sigma V_c} < 0.85. \quad 30$$

For determining ΣV_p the "electron microprobe analysis" method can very suitably be used.

The present patent application therefore relates to a process for the preparation of hydrocarbons by catalytic reaction of carbon monoxide with hydrogen, in which a mixture of carbon monoxide and hydrogen is contacted at elevated temperature and pressure with a catalyst comprising cobalt supported on a carrier, and in which the cobalt is distributed over the carrier in such a manner as to satisfy the relation

$$\frac{\Sigma V_p}{\Sigma V_c} < 0.85, \text{ wherein } \Sigma V_p \text{ and } \Sigma V_c \text{ have the meanings given hereinabove.}$$

- 40 Catalysts having a suitable inhomogeneous cobalt distribution can be prepared in a simple manner by keeping particles of a porous carrier immersed in water for about 30 minutes and, upon dripdrying, keeping the water-saturated carrier several times – each time for about 30 seconds – immersed in a solution of a cobalt salt in water, with the cobalt-loaded carrier being dried and calcined after each immersion.

- The catalysts used in the process according to the invention contain cobalt supported on a carrier. Very suitable carriers are, inter alia, silica, alumina and silica-alumina. Preference is given to the use of silica as carrier. The quantities of cobalt present on the catalysts may vary between wide ranges. Preferably use is made of catalysts which contain 3-60 parts by weight of cobalt per 100 parts by weight of carrier material. The catalysts used in the process according to the invention preferably include one or more promoters. Suitable promoters for the present cobalt catalysts are iron, magnesium, zinc and thorium. Preferably use is made of catalysts containing zirconium, titanium, chromium or ruthenium as promoter. Special preference is given to the use of zirconium as promoter. The preferred quantities of promoter present in the cobalt catalysts are dependent on the way in which it has been deposited. In the case of catalysts in the preparation of which the cobalt was deposited on the carrier first, and the promoter next, preference is given to catalysts comprising 0.1-5 parts by weight of the promoter per 100 parts by weight of carrier. In the case of catalysts in the preparation of which the promoter was deposited on the carrier first, and the cobalt next, preference is given to catalysts comprising 5-40 parts by weight of the promoter per 100 parts by weight of carrier.

- In the process according to the invention it is essential that a catalyst be used in which the cobalt is inhomogeneously distributed over the carrier in the correct manner. If, in addition to cobalt, the catalyst comprises a promoter, such as zirconium, the latter may be distributed over the carrier either homogeneously or inhomogeneously. Homogeneous distribution of the promoter will occur when the promoter is deposited on the carrier by way of conventional impregnation, either preceding or following the deposition of the cobalt on the carrier. Inhomogeneous distribution of the promoter may occur when the cobalt and the promoter are deposited simultaneously by co-impregnation, special measures having been taken to bring about the desired inhomogeneous distribution of cobalt over the carrier.

- 65 Before becoming eligible for use in the preparation of hydrocarbons from a H_2/CO mixture, the cobalt 65

catalysts should be activated. This activation can suitably be carried out by contacting the catalysts at a temperature between 200 and 350°C with hydrogen or a hydrogen-containing gas.

The conversion of the H₂/CO mixture into hydrocarbons according to the invention is preferably carried out at a temperature of 125-350°C and in particular of 175-275°C and a pressure of 5-100 bar and in particular of 10-75 bar. Further, the conversion is preferably carried out by contacting the H₂/CO mixture with a catalyst which is present in the form of a fixed bed having an external surface area (S_a) between 5 and 70 cm²/ml. In this case it is particularly preferred to use a catalyst for which

$$0.03 \times \sqrt{S_E} < \frac{\sum V_p}{\sum V_c} < 0.3 \times \sqrt{S_E}$$

H₂/CO mixtures which are eligible to be converted into hydrocarbons according to the invention can very suitably be obtained by steam reforming or partial oxidation starting from light hydrocarbons, such as natural gas.

The H₂/CO mixture which is converted into hydrocarbons according to the invention preferably has a H₂/CO molar ratio higher than 1.5. If the feed has a H₂/CO molar ratio lower than 1.5, it is preferred to increase the latter to a value lying between 1.5 and 2.5 and in particular between 1.75 and 2.25, before the feed is contacted with the cobalt catalyst. The H₂/CO molar ratio of hydrogen-poor H₂/CO mixtures can be increased by, inter alia, addition of hydrogen, removal of carbon monoxide, mixing with a hydrogen-rich H₂/CO mixture or by subjecting the hydrogen-poor H₂/CO mixture to the CO-shift reaction.

The process according to the invention can suitably be used as an independent process in which unconverted synthesis gas can be recirculated, if desired. Further, the process according to the invention can very suitably be used as the first step in a two-step process for the preparation of middle distillates from H₂/CO mixtures. For it has been found that catalysts containing silica, alumina or silica-alumina as carrier and cobalt together with zirconium, titanium, chromium and/or ruthenium as catalytically active metals, which catalysts have been prepared by depositing the metals concerned on the carrier material by impregnation, yield a product substantially consisting of unbranched paraffins whose high-boiling part can be converted in high yield into middle distillates by subjecting it to a hydrocracking treatment.

Although in the preparation of middle distillates from the product obtained over the cobalt catalyst the part of the product whose initial boiling point lies above the final boiling point of the heaviest middle distillate desired as end product will do as feed for the hydrocracking, the total C₈⁺ fraction of the product prepared over the cobalt catalyst may also be used for the purpose, if desired.

The hydrocracking is carried out by contacting the fraction to be treated at elevated temperature and pressure and in the presence of hydrogen with a catalyst containing one or more Group VIII noble metals on a carrier. The hydrocracking catalyst used by preference is a catalyst comprising 0.2-1 %w of platinum or palladium supported on silica-alumina as carrier. The hydrocracking treatment is preferably carried out at a temperature of 250-350°C and a pressure of 10-75 bar.

The invention is now illustrated with the aid of the following example.

EXAMPLE

40 Catalyst preparation

Three Co/Zr/SiO₂ catalysts (catalysts 1-3) were prepared as follows, starting from a spherical silica carrier dried at 120°C.

Catalyst 1

The silica carrier was contacted at a temperature of 20°C for 15 minutes with a solution of cobalt nitrate in water. The quantity of solution used was such that its volume corresponded substantially with the pore volume of the carrier. The solution has a viscosity, measured at 60°C, of 1.7 cS. After drying and calcining at 500°C the cobalt-loaded carrier was kept in contact with a solution of zirconium nitrate in water. In this case, too, the quantity of solution used corresponded substantially with the pore volume of the carrier. Finally the cobalt- and zirconium-loaded carrier was dried and calcined at 500°C.

Catalyst 2

The silica carrier was kept immersed in water of 20°C for 30 minutes. After dripdrying the water-saturated carrier was immersed three times – each time for 30 seconds – at a temperature of 20°C in the same solution of cobalt nitrate in water as was used in the preparation of catalyst 1. After each immersion the material was dried and calcined at 500°C. Subsequently, zirconium was deposited on the cobalt-loaded carrier in a way identical to that described for the preparation of catalyst 1.

Catalyst 3

This catalyst was prepared in substantially the same way as catalyst 2, the difference being that in the present case four immersions in the cobalt nitrate solution were performed. Further information concerning catalysts 1-3 is given in the table.

Catalyst testing

65 Catalysts 1-3 were used in three experiments (experiments 1-3) in the preparation of hydrocarbons from a

mixture of carbon monoxide and hydrogen having a H_2/CO molar ratio 2. The experiments were carried out at a pressure of 20 bar and a space velocity of $600 \text{ Nl.l}^{-1}.\text{h}^{-1}$ in a reactor containing a fixed catalyst bed having an S_E of $13 \text{ cm}^2/\text{ml}$. Preceding the testing the catalysts were activated by subjection to a hydrotreatment at 250°C . Further information on experiments 1-3 is given in the table.

5 Of the experiments mentioned in the table only experiments 2 and 3 are experiments according to the invention. These experiments, which were carried out using a catalyst for which was carried out using a catalyst for which

$$\frac{\Sigma V_p}{\Sigma V_c} < 0.85,$$

10 led to relatively high C_5^+ selectivities. Experiment 1 falls outside the scope of the invention and has been included in the patent application for comparison. The C_5^+ selectivity found in this experiment, which was carried out using a catalyst for which

$$\frac{\Sigma V_p}{\Sigma V_c} > 0.85, \text{ was considerably lower.}$$

TABLE

20	Experiment No.	1	2	3	20
	Catalyst No.	1	2	3	
25	Cobalt load, g Co/100 g SiO_2	22	18	22	25
	Zirconium load, g Zr/100 g SiO_2	0.9	0.9	0.9	
	ΣV_p ΣV_c	0.88	0.75	0.73	
30	Temperature of synthesis gas conversion, $^\circ\text{C}$	230	235	225	30
	N1 synthesis gas converted per g Co per h	5.1	7.4	5.8	
35	C_5^+ selectivity, %w	59	65	66	35

CLAIMS

- 40 1. A process for the preparation of hydrocarbons by catalytic reaction of carbon monoxide with hydrogen, characterized in that a mixture of carbon monoxide and hydrogen is contacted at elevated temperature and pressure with a catalyst comprising cobalt supported on a carrier, the cobalt being distributed over the carrier in such a way as to satisfy the relation
- 45 $\frac{\Sigma V_p}{\Sigma V_c} < 0.85,$
- wherein ΣV_c represents the total volume of the catalyst particles under consideration and ΣV_p is found by totalizing the peel volumina present in the catalyst particles, when the latter is taken to be composed of a
- 50 kernel surrounded by a peel, the kernel being of such a shape that at every point of the kernel perimeter the shortest distance (d) to the perimeter of the peel is the same, and that d is equal for all catalyst particles under consideration and has been chosen such that the quantity of cobalt present in ΣV_p is 90% of the quantity of cobalt present in ΣV_c .
- 55 2. A process as claimed in claim 1, characterized in that the catalyst comprises silica, alumina or silica-alumina as carrier.
3. A process as claimed in claim 1 or 2, characterized in that the catalyst comprises 3-60 parts by weight of cobalt per 100 parts by weight of carrier.
4. A process as claimed in claim 3, characterized in that the catalyst comprises 5-50 parts by weight of cobalt per 100 parts by weight of carrier.
- 60 5. A process as claimed in any one of claims 1-4, characterized in that the catalyst comprises one or more promoters chosen from zirconium, titanium, chromium and ruthenium.
6. A process as claimed in claim 5, characterized in that per 100 parts by weight of carrier the catalyst comprises either 0.1-5 parts by weight of promoter, if during the preparation the cobalt was deposited first and the promoter next, or 5-40 parts by weight of promoter, if during the preparation the promoter was
- 65 deposited first and the cobalt next.

7. A process as claimed in any one of claims 1-6, characterized in that the catalyst comprises silica as carrier and zirconium as promoter.
8. A process as claimed in any one of claims 1-7, characterized in that it is carried out at a temperature of 125-350°C and a pressure of 5-100 bar.
- 5 9. A process as claimed in claim 8, characterized in that it is carried out at a temperature of 175-275°C and a pressure of 10-75 bar. 5
10. A process as claimed in any one of claims 1-9, characterized in that the H₂/CO mixture is contacted with a catalyst which is present in the form of a fixed bed having an external surface area (S_E) between 5 and 70 cm²/l.
- 10 11. A process as claimed in claim 10, characterized in that a catalyst is used for which 10
- $$0.03 \times \sqrt{S_E} < \frac{\sum V_E}{\sum V_G} < 0.3 \times \sqrt{S_E}.$$
12. A process for the preparation of hydrocarbons by catalytic reaction of carbon monoxide with 15 hydrogen as claimed in claim 1 substantially as hereinbefore described with reference to the Example. 15