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(71) Applicant

Shell Internationale Research Maatschappij BV,
(Netherlands),
Carel van Bylandtlaan 30, The Hague, The Netherlands

(72) Inventor

Swan Tiong Sie

(74) Agent and/or Address for Service

K. R. I. Hunter,
4 York Road, London SE1 7NA

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(58) Field of search
C5E

(54) Process for the preparation of hydrocarbons

(57) Syngas is subjected to Fischer-Tropsch synthesis over a special Co/ at least one of Zr/Ti/Gr and silica, aluminic or silica/alumina catalyst and the C₂₀ fraction of the synthesized product is converted into linear C₁₀-C₂₀ olefins by mild thermal cracking.

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SPECIFICATION

Process for the preparation of hydrocarbons

- 5 The invention relates to a process for the preparation of linear olefins having at least 10 and at most 20 carbon atoms per molecule.
- Linear olefins having at least 10 and at most 20 carbon atoms per molecule (hereinafter referred to as "linear" $C_{10}-C_{20}$ olefins) are valuable starting materials for the preparation of synthetic detergents. Said olefins can be obtained by mild thermal cracking of mixtures of linear paraffins having at least 20 carbon atoms per molecule (hereinafter referred to as "linear $C_{20}+$ paraffins"). Linear $C_{20}+$ paraffins, together with branched $C_{20}+$ paraffins are found in heavy mineral oil fractions, such as lubricating oil fractions. The paraffins can be separated from said mineral oil fractions by cooling. From the paraffin mixtures obtained the desired linear paraffins can be isolated by way of fractional crystallisation or complexing with urea. The linear $C_{20}+$ paraffins thus obtained are generally contaminated with sulphur- and nitrogen compounds from the mineral oil, as well as cyclic compounds. Preparatory to being suitable for use as feed for the preparation of linear $C_{10}-C_{20}$ olefins by mild thermal cracking the $C_{20}+$ paraffins should be freed from these contaminants.
- Linear $C_{20}+$ paraffins which can suitably be used as starting material for the preparation of linear $C_{10}-C_{20}$ olefins by way of mild thermal cracking may also be synthesized starting from a mixture of carbon monoxide and hydrogen. In this what is called Fischer-Tropsch synthesis a H_2/CO mixture is contacted at elevated temperature and pressure with a catalyst comprising one or more metals from the iron group together with one or more promoters and a carrier material. The preparation of these catalysts can suitably be carried out by the known techniques, such as precipitation, impregnation, kneading and melting. As compared with waxy heavy mineral oil fractions the products prepared by the Fischer-Tropsch synthesis have the advantage that they contain virtually no sulphur- and nitrogen compounds and cyclic compounds. Nevertheless the use of the products obtained over the usual Fischer-Tropsch catalysts for the preparation of linear $C_{10}-C_{20}$ olefins has two drawbacks which are connected with their composition. In the first place these products contain but a relatively small amount of $C_{20}+$ compounds as compared to the quantities of $C_{10}-C_{20}$ compounds present. Furthermore the $C_{20}+$ compounds are made up to a considerable extent of branched paraffins, branched and unbranched olefins and oxygen-containing compounds.
- Recently there has been found a class of Fischer-Tropsch catalysts which have the property of yielding a product in which considerably more $C_{20}+$ compounds are present than in the products prepared by the usual Fischer-Tropsch catalysts, which $C_{20}+$ compounds consist virtually exclusively of linear paraffins. The Fischer-Tropsch catalysts belonging to the above-mentioned class contain silica, alumina or silica-alumina as carrier materials, and cobalt together with zirconium, titanium and/or chromium as catalytically active metals, in such quantities that per 100 pbw of carrier material the catalysts comprise 3-60 pbw of cobalt and 0.1-100 pbw of zirconium, titanium, and/or chromium. The catalysts are prepared by depositing the metals involved on the carrier material by kneading and/or impregnation. For further information concerning the preparation of these catalysts by kneading and/or impregnation reference may be made to Netherlands patent application No. 8301922, recently filed by the Applicant. Considering the composition of the product prepared over the cobalt catalysts it is extremely attractive to separate from the product a heavy fraction substantially consisting of $C_{20}+$ paraffins and to convert at least part of this heavy fraction by mild thermal cracking into a mixture of hydrocarbons substantially consisting of linear olefins and containing the desired $C_{10}-C_{20}$ olefins.
- 50 The present patent application therefore relates to a process for the preparation of linear $C_{10}-C_{20}$ olefins in which a mixture of carbon monoxide and hydrogen is converted into a mixture of hydrocarbons substantially consisting of linear paraffins by contacting it at elevated temperature and pressure with a catalyst comprising 3-60 pbw of cobalt and 0.1-100 pbw of at least one other metal chosen from the group formed by zirconium, titanium and chromium per 100 pbw of silica, alumina or silica-alumina carrier, which catalyst has been prepared by kneading and/or impregnation, in which from the paraffin mixture thus prepared a heavy fraction is separated which consists substantially of $C_{20}+$ paraffins, and in which at least this heavy fraction is converted by mild thermal cracking into a mixture of hydrocarbons which consists substantially of linear olefins and contains the desired $C_{10}-C_{20}$ olefins.
- In the process according to the invention the starting material should be a H_2/CO mixture. Suitable H_2/CO mixtures can be prepared by the gasification of heavy carbonaceous materials, such as coal and residual mineral oil fractions. It is preferred to start from a H_2/CO mixture which has been obtained by the steam reforming or partial oxidation of light hydrocarbons, in particular natural gas.
- In the process according to the invention preference is given to the use of the cobalt catalysts which form the subject matter of Netherlands patent application No. 8301922. They are catalysts which satisfy the relation:

$$(3 + 4 R) > L/S > (0.3 + 0.4 R), \text{ wherein}$$

L = the total quantity of cobalt present on the catalyst, expressed as mg Co/ml catalyst,

S = the surface area of the catalyst, expressed as m^2/ml catalyst, and

R = the weight ratio of the quantity of cobalt deposited on the catalyst by kneading to the total quantity of cobalt present on the catalyst.

In the process of the invention use is further preferably made of cobalt catalysts which have been prepared by one of the three procedures mentioned hereinafter:

- 5 a) first cobalt is deposited in one or more steps by impregnation and subsequently the other metal is deposited in one or more steps, also by impregnation,
- b) first the other metal is deposited in one or more steps by impregnation and subsequently the cobalt is deposited in one or more steps, also by impregnation, and
- 10 c) first cobalt is deposited in one or more steps by kneading and subsequently the other metal is deposited in one or more steps by impregnation.

In the process according to the invention use is further preferably made of cobalt catalysts containing 15-50 pbw of cobalt per 100 pbw of carrier. The preferred quantity of other metal present in the cobalt catalysts depends on the way in which this metal has been deposited. In the case of catalysts where first cobalt has been deposited on the carrier, followed by the other metal, preference is given to catalysts 15 containing 0.1-5 pbw of the other metal per 100 pbw of carrier. In the case of catalysts where first the other metal has been deposited on the carrier, followed by the cobalt, preference is given to catalysts containing 5-40 pbw of the other metal per 100 pbw of carrier. Preference is given to zirconium as the other metal and to silica as carrier material.

In the process according to the invention the conversion the H_2/CO mixture is preferably carried out a 20 temperature of 125-350°C and a pressure of 5-100 bar and in particular at a temperature of 175-275°C and a pressure of 10-75 bar. The mild thermal cracking which according to the invention is applied to at least part of the heavy fraction of the product prepared over the cobalt catalyst is preferably carried out in the presence of steam. Further the mild thermal cracking is preferably carried out at a temperature of 535-675°C, a pressure of 1-5 bar abs., a residence time of 0.5-15 seconds and in the presence of a quantity of 25 steam which is at most 40%w, calculated on the hydrocarbon feed, and in particular at a temperature of 540-600°C, a residence time of 2-10 seconds and in the presence of a quantity of steam of 3-20 %w, calculated on the hydrocarbon feed.

In the process according to the invention the product obtained by mild thermal cracking consisting substantially of linear olefins is divided into a light C_3 - fraction, the C_{10} - C_{20} fraction desired as end prod- 30 uct, and a heavy C_{21} + fraction. The yield of linear C_{10} - C_{20} olefins may be increased by recycling at least part of the heavy C_{21} + fraction to the mild thermal cracking, or by dividing the light C_3 - fraction into a C_4 -fraction and a C_5 - C_9 fraction, subjecting at least part of the latter fraction, together with at least part of the heavy C_{21} + fraction to a combination of isomerization and disproportionation in order to prepare a mixture of linear olefins, and separating from the olefin mixture thus obtained an additional quantity of 35 C_{10} - C_{20} linear olefins. From the C_4 - fractions which remains after the separation of the C_3 - fraction, there can be separated ethene, from which linear olefins can be prepared by oligomerization, part of which linear olefins consist of C_{10} - C_{20} olefins. The C_5 - and C_{21} + olefins present in the mixture can be converted by means of the afore-mentioned combination of isomerization and disproportionation into a mixture of linear olefins from which C_{10} - C_{20} olefins can be separated.

40 In the process according to the invention a further increase of the yield of linear C_{10} - C_{20} olefins can be realised starting from the C_{15} - fraction obtained in the hydrocarbon synthesis over the cobalt catalyst, or from lighter fractions separated therefrom. By subjecting these fractions, which consist substantially of linear paraffins to steam cracking, a mixture of lower olefins can be obtained which consists substantially of ethene. The ethene can be oligomerized to prepare a mixture of linear olefins which consists partly of 45 C_{10} - C_{20} olefins. The C_6 - and C_{21} + olefins formed in the oligomerization can be converted by the afore-mentioned combination of isomerization and disproportionation into a mixture of linear olefins from which the desired C_{10} - C_{20} olefins can be separated. An increase of the yield of linear C_{10} - C_{20} olefins, starting from the C_{15} - fraction obtained in the hydrocarbon synthesis over the cobalt catalyst, can also be realised by separating from the C_{15} - fraction a heavy fraction and subjecting it to dehydrogenation or 50 chlorination, followed by dehydrochlorination. From the C_{10} - C_{15} or the C_5 - C_9 fraction of the product obtained over the cobalt catalyst can thus be prepared linear C_{10} - C_{19} or C_5 - C_{19} olefins. The C_5 - C_{19} olefins present in the mixture of C_5 - C_{19} olefins can suitably be used as feed components in the disproportionation mentioned hereinbefore. The afore-mentioned processes for the preparation of linear C_{10} - C_{20} olefins, starting from the C_{15} - fraction obtained in the hydrocarbon synthesis over the cobalt catalyst, can very suitably be combined by dividing the C_{15} - fraction into a light and a heavy fraction (for instance a C_4 - and a C_5 - 55 C_{15} fraction, or a C_5 - and a C_{10} - C_{15} fraction), and converting the light fraction by steam cracking/oligomerization and the heavy fraction by dehydrogenation or chlorination/dehydrochlorination.

In the present patent application there has thus far only been mention of the use of the product obtained over the cobalt catalyst as feed for the preparation of linear C_{10} - C_{20} olefins. According to the inven- 60 tion, to this end at least part of the C_{21} + fraction should be subjected to mild thermal cracking. Optionally the entire C_{21} + fraction may be converted in this way. In addition, as described hereinbefore, part or all of the C_{15} - fraction can be used for the preparation of linear C_{10} - C_{20} olefins. In view of the special composition of the product obtained over the cobalt catalyst which consists virtually entirely of linear paraffins, this product is also excellently suitable for a number of other applications, which can be combined with 65 the process according to the invention. To this end use may be made either of part of the C_{21} + fraction

or of at least part of the C_{10} -fraction.

In addition to its use according to the invention as feed for the preparation of linear C_{10} - C_{20} olefins by mild thermal cracking, the $C_{20}+$ fraction is very suitable for the uses following:

- 1) Valuable solid paraffins can be separated from the $C_{20}+$ fraction by fractional crystallization.
- 2) A mixture of lower olefins substantially consisting of ethene can be obtained from the $C_{20}+$ fraction by steam cracking.
- 3) A product from which a lubricating oil with a high viscosity index can be obtained from the $C_{20}+$ fraction by catalytic hydro-isomerization.

- 4) The $C_{20}+$ fraction can be converted into middle distillates by catalytic hydrocracking.
- 10 In addition to its use as feed for the preparation of linear C_{10} - C_{20} olefins the C_{10} -fraction is very suitable for the uses following:

- 1) A mixture of lower olefins substantially consisting of ethene can be obtained from the C_{10} -fraction by steam cracking.
- 2) By treating the C_{10} - C_{15} fraction at an elevated temperature with a peroxide of the general formula $R-O-O-R'$, wherein R and R' represent alkyl, aryl or acyl groups, said fraction can be converted into a product from which a lubricating oil with a high viscosity index can be separated.
- 3) Certain fractions with a narrow boiling range which are present in the C_{5} - C_{11} fraction can be suitably used as special solvents either such as they are or after a mild hydrogenation or hydro-isomerization carried out to convert minor amounts of olefins and/or oxygen-containing compounds, or to introduce some branching. In this connection may be mentioned extraction liquors for oil seeds, spraying oils for insecticides and pesticides and as solvents for medicinal and pharmaceutical uses and in the food-stuff industry.

- The afore-mentioned steam cracking for the preparation of a mixture of lower olefins substantially consisting of ethene may very suitably be carried out at a temperature of 700-1000°C, a pressure of 1-5 bar abs., a residence time of 0.04-0.5 seconds and in the presence of a quantity of steam which amounts to 20-100 %w, calculated on hydrocarbon feed.

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

Example

- 30 Five hydrocarbon synthesis experiments were carried out by using the following catalysts.

Catalyst A

- This catalyst comprised 10 pbw of iron, 5 pbw of copper, 2 pbw of potassium and 30 pbw of kieselguhr, and had been prepared by precipitation of iron and copper from an aqueous solution by using potassium carbonate, while kieselguhr was being added.

Catalyst B

- This catalyst comprised 97.5 pbw of iron, 2.5 pbw of aluminium and 0.5 pbw of potassium, and had been prepared by melting a mixture of Fe_3O_4 and the oxides of aluminium and potassium in an arc.

Catalyst C

- This catalyst comprised 100 pbw of cobalt, 5 pbw of thorium oxide, 7.5 pbw of magnesium oxide and 200 pbw of kieselguhr, and had been prepared by precipitation of cobalt and thorium from an aqueous solution, while kieselguhr was being added.

Catalyst D

- This catalyst comprised 25 pbw of cobalt and 0.9 pbw of zirconium per 100 pbw silica, and had been prepared by kneading a silica carrier in a solution of cobalt nitrate in water, followed by single-step impregnation of the cobalt-loaded carrier with a solution of zirconylchloride in water.

Catalyst E

- This catalyst comprised 23 pbw of cobalt and 17 pbw of zirconium per 100 pbw of silica, and had been prepared by three-step impregnation of a silica carrier with solution of zirconiumtetra n-propoxide in a mixture of n-propanol and benzene, followed by single-step impregnation of the zirconium-loaded carrier with solution of cobalt nitrate in water.

- During the preparation of Catalysts D and E, such a quantity of solution was used in each impregnation step that its volume corresponds substantially with the pore volume of the carrier. After each impregnation step the solvent was removed by heating and the material was calcined at 500°C. When a kneading step was used, the quantity of solution used had a volume substantially corresponding with 150% of the pore volume of the carrier. When a kneading step was used, the mixture was kneaded in a kneading machine for three hours. During the kneading a small portion of the solvent was removed by heating. After the kneading step the paste obtained was recovered from the kneading machine, the remainder of the solvent was removed by heating, and the material was ground and calcined at 500°C.

Hydrocarbon synthesis experiments (1-5)

After Catalysts A-E had been activated by means of treatment with a hydrogen-containing gas at 250°C they were used in the preparation of hydrocarbons from a mixture of carbon monoxide and hydrogen. The experiments were carried out in a reactor containing a fixed catalyst bed. The conditions under which the experiments were carried out and the results of these experiments are given in Table I. Of these experiments only Experiments 4 and 5 are part of the invention. Experiments 1-3 fall outside the scope of the invention. They have been included in the patent application for comparison.

Cracking experiment (6)

The C₂₀+ fraction of the product prepared in accordance with Experiment 4 was cracked in the presence of steam at a temperature of 575°C, a pressure of 1 bar, a space velocity of 3.2 kg.1⁻¹.h⁻¹, calculated on the volume of the cracking zone, a steam dose rate of 6.5 %w, calculated on feed and a nominal residence time in the cracking zone of 2.5 seconds. After cooling and separation of the condensed water a product was obtained of which 5 %w consisted of a gas fraction, 14 %w of a light liquid fraction substantially boiling below 300°C, and 81 %w of a residual fraction substantially boiling above 300°C. The gas fraction obtained in the cracking was made up of hydrogen and light hydrocarbons. The cracking gas comprised 35 %v ethene and 17 %v propene. The light liquid fraction consisted substantially of linear C₅-C₂₀ olefins. The olefins content was 95% and the α-olefins content 90%.

Cracking experiment (7)

The C₈-C₉ fraction of the product prepared according to experiment 4 was cracked in the presence of steam at an average temperature of 760°C, an average pressure of 1.5 bar, a residence time of 0.5 seconds and a steam/ hydrocarbon weight ratio of 0.5. The composition of the product obtained is as given in Table II.

TABLE I

Experiment No.	1	2	3	4	5
Catalyst No.	A	B	C	D	E
Temperature, °C	230	320	190	220	204
Pressure, bar	20	20	1n20	20	
H ₂ /CO volume ratio	1.7	2.5	2.0	2.0	3.0
Space velocity, N1.1 ⁻¹ .h ⁻¹	1750	1750	75	500	900
Conversion H ₂ +CO, %v	22	30	70	75	62
<i>Product distribution, %w</i>					
Gas (C ₁ -C ₄)	22.6	54.1	28.5	18.0	23.0
Gasoline (C ₅ -200°C)	28.3	31.9	42.6	15.1	19.0
Kerosine+gasoil (200-350°C)	19.5	2.5	19.5	28.4	22.4
Waxy residue (350°C+)	26.4	0	8.0	38.0	35.4
Water-soluble oxygen compounds	3.4	11.3	1.5	0.5	0.2
<i>Properties of C₈+ product</i>					
Olefins content, %mol	50	80	34	8	2
Aromatic content, %mol	0.3	5.0	0.1	0	0
Linearity, %	90	50	60	95	97
(percentage linear paraffins and olefins calculated on total of paraffins and olefins)					
Number of C atoms in tertiary structure, %	1	5	4	0.2	0.1

TABLE II

Composition in %w of product prepared according to Experiment 7

5	Hydrogen	1	5
	Methane	14	
	Ethane	5	
	Ethene	40	10
10	Propane	0.5	
	Propene	14	
	C ₄	8	
	C ₅	5	
15	C ₆ +	12	15

CLAIMS

1. Process for the preparation of linear C₁₀-C₂₀ olefins, characterized in that a mixture of carbon monoxide and hydrogen is converted into a mixture of hydrocarbons substantially consisting of linear paraffins by contacting it at elevated temperature and pressure with a catalyst comprising 3-60 pbw of cobalt and 0.1-100 pbw of at least one other metal chosen from the group formed by zirconium, titanium and chromium per 100 pbw of silica, alumina or silica-alumina carrier, which catalyst has been prepared by kneading and/or impregnation, in which from the paraffin mixture thus prepared a heavy fraction is separated which consists substantially of C₂₀+ paraffins, and in which at least this heavy fraction is converted by mild thermal cracking into a mixture of hydrocarbons which consists substantially of linear olefins and contains the desired C₁₀-C₂₀ olefins.
2. A process as claimed in claim 1, characterized in that a H₂/CO mixture is used which has been obtained, starting from light hydrocarbons, by steam reforming a partial oxidation.
3. A process as claimed in claim 2, characterized in that a H₂/CO mixture is used which has been obtained starting from natural gas.
4. A process as claimed in any one of claims 1-3, characterized in that a cobalt catalyst is used which satisfies the relation

$$(3 + 4 R) > L/S > (0.3 + 0.4 R), \text{ wherein}$$

L = the total quantity of cobalt present on the catalyst, expressed as mg Co/ml catalyst,
S = the surface area of the catalyst, expressed as m²/ml catalyst, and

R = the weight ratio of the quantity of cobalt deposited on the catalyst by kneading to the total quantity of cobalt present on the catalyst.
5. A process as claimed in any one of claims 1-4, characterized in that a cobalt catalyst is used which, per 100 pbw of carrier, comprises 15-50 pbw of cobalt and either 0.1-5 pbw of the other metal when during the preparation cobalt was deposited first and the other metal next, or 5-40 pbw of the other metal when during the preparation the other metal was deposited first and the cobalt next.
6. A process as claimed in any one of claims 1-5, characterized in that a cobalt catalyst is used which comprises zirconium as other metal and silica as carrier.
7. A process as claimed in any one of claims 1-6, characterized in that the conversion of the H₂/CO mixture is carried out at a temperature of 125-350°C and a pressure of 5-100 bar.
8. A process as claimed in claim 7, characterized in that the conversion of the H₂/CO mixture is carried out at a temperature of 175-275°C and a pressure of 10-75 bar.
9. A process as claimed in any one of claims 1-8, characterized in that the mild thermal cracking of the heavy fraction of the product prepared over the cobalt catalyst is carried out in the presence of steam.
10. A process as claimed in claim 9, characterized in that the mild thermal cracking is carried out at a temperature of 535-675°C, a pressure of 1-5 bar abs., a residence time of 0.5-15 seconds and in the presence of a quantity of steam which amounts to at most 40 %w, calculated on the hydrocarbon feed.
11. A process for the preparation of linear C₁₀-C₂₀ olefins and, substantially as described hereinbefore and in particular with reference to Experiments 4, 5, 6 and 7.
12. Linear C₁₀-C₂₀ olefins, whenever prepared according to a process as claimed in any one of claims 1-11.