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(54) Title: ENHANCED CATALYST AND PROCESS FOR CONVERTING SYNTHESIS GAS TO LIQUID MOTOR FUELS			
(57) Abstract The conversion of synthesis gas to liquid molar fuels by means of a cobalt Fischer-Tropsch catalyst composition is enhanced by the addition of molybdenum, tungsten or a combination thereof as an additional component of said composition. The presence of the additive component increases the olefinic content of the hydrocarbon products produced. The catalyst composition can advantageously include a support component, such as a molecular sieve, co-catalyst/support component or a combination of such support components.			

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ENHANCED CATALYST AND PROCESS FOR
CONVERTING SYNTHESIS GAS TO LIQUID MOTOR FUELS

Statement

5 The Government of the United States of
America has rights to this invention pursuant to
Contract No. DE-AC22-81PC40077 awarded by the U.S.
Department of Energy.

Background of the Invention

10 Field of the Invention - The invention
relates to the conversion of synthesis gas to
hydrocarbons. More particularly, it relates to the
conversion of such synthesis gas to C_5^+
hydrocarbons suitable for use as liquid motor fuels.

15 Description of the Prior Art - It is well
known in the art that synthesis gas, i.e., hydrogen
and carbon monoxide, can be converted to
hydrocarbons in the presence of a variety of
transition metal catalysts. Thus, certain Group
VIII metals, particularly iron, cobalt, ruthenium
20 and nickel, are known to catalyze the conversion of
CO and hydrogen, also referred to as syngas, to
hydrocarbons. Such metals are commonly called
Fischer-Tropsch catalysts. While the use of nickel
preferentially produces methane upon conversion of
25 syngas, the use of iron, cobalt and ruthenium tends
to produce hydrocarbon mixtures consisting of
hydrocarbons having a larger carbon number than
methane, as determined by a number of analytical
means including mass spectrographic analysis of
30 individual components and the boiling point curve
method. At higher reaction temperatures, all

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Fischer-Tropsch catalysts tend to produce gaseous hydrocarbons, and it is readily feasible to select processing conditions to produce methane as the principal product. At lower temperatures, and
5 usually at higher pressures, however, iron, cobalt and ruthenium produce hydrocarbon mixtures consisting of larger hydrocarbons. These products usually contain very long straight-chain hydrocarbon molecules that tend to precipitate as wax. Such wax
10 material, boiling well beyond the boiling range of motor fuels, typically constitutes a significant fraction of the product produced in such catalytic conversion operations. Fischer-Tropsch catalysts have not been advantageously employed in the
15 production of liquid hydrocarbon motor fuels, therefore, instead commonly producing either principally gaseous hydrocarbons, on the one hand, or hydrocarbons containing an unacceptably large amount of wax on the other. In addition, the
20 gasoline boiling hydrocarbon fraction that has been produced has an unacceptably low octane number.

In light of such circumstances, efforts have been made to improve the performance of Fischer-Tropsch catalysts for use in various desired
25 syngas conversions. For example, the Breck et al. patent, U.S. 3,013,990, discloses the use of zeolitic molecular sieves containing a Fischer-Tropsch catalyst as improved catalyst compositions. Thus, Type A, X and Y molecular
30 sieves loaded with iron or cobalt are shown to be suitable Fischer-Tropsch hydrocarbon synthesis catalysts, as for the production of methanol from

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syngas. Also with respect to the conversion of syngas, Fraenkel et al., U.S. 4,294,725, teach that zeolites A and Y loaded with cobalt, incorporated by ion exchange and reduced in-situ with cadmium, serve
5 as useful catalysts of the Fischer-Tropsch type. Those skilled in the art will appreciate that such catalyst materials tend to be relatively expensive and, in any event, do not produce hydrocarbon products advantageous for use as liquid motor fuels.

10 Efforts have also been made to improve Fischer-Tropsch catalyst performance by preparing intimate mixtures of Fischer-Tropsch metals, such as iron, with an acidic crystalline aluminosilicate, such as ZSM-5. The Chang et al. patents, U.S.
15 4,086,262, and U.S. 4,096,163, disclose such catalyst compositions employed in the conversion of synthesis gas to hydrocarbon mixture useful in the manufacture of heating fuels, gasoline, aromatic hydrocarbons and chemical intermediates. When it is
20 desired to convert syngas specifically to hydrocarbons boiling in the jet fuel + diesel oil boiling range, however, such an approach is not suitable, experiencing an effective limitation at C_{10} carbon number as was the case using ZSM-5 in
25 methanol conversion, as disclosed in the Owen et al. patent, U.S. 3,969,426.

 While iron is the currently preferred Fischer-Tropsch catalyst component for use in syngas conversion operations, cobalt had originally been
30 preferred because of its various desirable properties. Thus, cobalt has a higher level of catalytic activity in syngas conversion operations

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as well as a better selectivity to total motor fuels than is obtained using iron. Cobalt has certain product quality disadvantages, however, that have tended to discourage its use for syngas conversion operations. Thus, the hydrocarbon products obtained using cobalt catalysts are generally more paraffinic and waxy than the corresponding products obtained using iron as the Fischer-Tropsch catalyst. Such waxy products are much more difficult to upgrade, as by the use of a shape selective component in the Fischer-Tropsch catalyst composition in accordance with known practice, than would be a more olefinic hydrocarbon conversion product of syngas conversion operations.

It is desirable, therefore, that improvements be made in the art to enable cobalt to be more advantageously employed as a Fischer-Tropsch catalyst for syngas conversion operations. The prior art developments relating to the use of cobalt catalysts for applications other than Fischer-Tropsch catalysts do not appear relevant to the problems associated with the Fischer-Tropsch conversion of syngas to liquid motor fuels. Thus, cobalt-molybdenum catalysts supported on alumina are the commonly employed commercial hydrotreating (hydrode-sulfurization) catalysts. Such catalysts, generally containing 3-5% CoO and 15% MoO₃ on Al₂O₃, are not particularly relevant to Fischer-Tropsch catalysis. In another area of prior art activity, molybdenum and tungsten have been employed in Fischer-Tropsch synthesis reactions.

At a 1982 Material Research Society meeting, A. Brenner reported the use of molybdenum and tungsten as Fischer-Tropsch metals. Thus, molybdenum salts were reduced at a high temperature (1000°C), and the reduced molybdenum was found to act as a very low activity Fischer-Tropsch metal. A somewhat more active catalyst can be formed by reducing molybdenum or tungsten carbonyl. Molybdic acid has also been tested as a promoter for iron Fischer-Tropsch catalysts as reported in the Fischer-Tropsch and Related Synthesis by H. Storch, N. Golumbic and R. Anderson, John Wiley & Sons, N.Y. 1951, however, the molybdic acid did not improve the activity of the iron catalyst. Storch et al also reported the testing of tungsten oxide promoters for iron Fischer-Tropsch catalysts, said promoters resulting in a shift of the product distribution toward high wax yields.

It is generally known in the art that manganese is effective in increasing the olefin content of hydrocarbon products obtained upon syngas conversion using an iron Fischer-Tropsch catalyst. Manganese is not effective, however, in producing more olefins when a cobalt Fischer-Tropsch catalyst is employed. Despite the various activities carried out in the art as indicated above, there remains a desire in the art for improvements rendering cobalt a more satisfactory Fischer-Tropsch catalyst for syngas conversion than it is at the present time. What is thus desired in the art is the development of an additive and/or an operating technique that will have a similar effect with respect to cobalt as has manganese with respect to iron catalysts.

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It is an object of the invention, therefore, to provide an improved Fischer-Tropsch catalyst composition for use in the conversion of syngas to liquid motor fuels.

5 It is another object of the invention to provide an improved cobalt-based Fischer-Tropsch catalyst composition for said syngas conversion.

10 It is a further object of the invention to provide a cobalt Fischer-Tropsch syngas conversion catalyst and process capable of enhancing the olefinic content of the liquid hydrocarbon conversion products obtained.

15 With these and other objects in mind, the invention is hereinafter described in detail, the novel features thereof being particularly pointed out in the appended claims.

Summary of the Invention

20 The olefinic content of the hydrocarbon products obtained during syngas conversion operations using cobalt as a Fischer-Tropsch catalyst is increased by the addition of a particular additive component to a cobalt catalyst composition. The catalyst composition is
25 advantageously supported by a molecular sieve co-catalyst/support component capable of enhancing the desired conversion of syngas to liquid hydrocarbons useful or capable of conversion to desired motor fuels.

30 Detailed Description of the Invention

The objects of the invention are accomplished by the admixing of a particular

additive component with a cobalt-containing Fischer-Tropsch catalyst. Such additive is taken from the group consisting of molybdenum, tungsten and combinations thereof. As a result of the use of
5 such an additive, the use of cobalt as a syngas conversion catalyst is enhanced as the resulting hydrocarbon products obtained are found to have a desirably higher olefinic content than is obtained in the absence of the use of the additive
10 component. The suitability of the product liquid hydrocarbons obtained for use as motor fuels is thereby enhanced by the practice of the invention in conjunction with the use of cobalt with or without thorium promotion as a Fischer-Tropsch catalyst for
15 syngas conversion. The synthesis gas, or syngas, treated in accordance with the practice of the invention generally comprises a mixture of hydrogen and carbon monoxide, usually together with smaller amounts of carbon dioxide, methane, nitrogen or
20 other components as is well known in the art. Syngas is commonly produced by steam reforming of hydrocarbons or by the partial oxidation of coal and petroleum deposits, or by similar gasification of other carbonaceous fuels such as peat, wood and
25 cellulosic waste materials. The hydrogen/carbon oxide volume ratio of such syngas is desirably in the range of from about 0.2/1 to about 6.0/1 prior to conversion to liquid motor fuels as herein disclosed and claimed. This ratio can be adjusted,
30 if desired, by reaction of carbon monoxide with steam in the well-known water-gas shift reaction. If required, sulfur impurities can be removed from

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the syngas mixture by conventional means known in the art. It should also be noted that the syngas as described herein includes art-recognized equivalents, such as mixtures of carbon monoxide and steam, or of carbon dioxide and hydrogen, that can provide synthesis gas mixture by in-situ reaction under the operating conditions employed.

The invention as herein described is related to the use of cobalt admixed with the additive component referred to above, preferably thorium-promoted and preferably with a support component, particularly one that tends to further enhance the desired syngas conversion to liquid motor fuels as further described below. The additive component can be employed in an amount within the range of from about 1% to about 50 mole % based on the total amount of cobalt metal and said additive component in the catalyst composition, with an additive component concentration of from about 5% to about 25% being generally preferred for many applications.

In the practice of the invention, the cobalt component and the additive component can be combined in various ways, preferably by a method of combination that brings the cobalt component, i.e., thorium-promoted cobalt, and the additive component into intimate contact in the catalyst composition. A generally preferred method of incorporation is to impregnate the cobalt, preferably thorium-promoted cobalt, with a solution of a soluble molybdenum or tungsten compound. For example, ammonium heptamolybdate is a commercially available compound

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that is very soluble and suitable for purposes of the invention. Thorium-promoted cobalt oxide is a preferred source of cobalt. Coprecipitation of molybdenum or tungsten with the cobalt is also possible, but the resulting catalyst does not appear to have the extended lifetime capability achieved with respect to the preferred embodiments of the catalyst composition. A physical mixing of the cobalt with the additive component may also be possible, but is less likely to be effective for the desired purpose and is generally less preferred.

Synthesis gas conversion operations can be carried out in the practice of the invention with the Fischer-Tropsch catalyst composition as herein disclosed and claimed at a reaction temperature within the range of from about 150°C to about 400°C, preferably from about 240°C to about 320°C. The conversion operations can be carried out at any convenient pressure level, as from about 0 to about 1,000 psig, typically at from about 0 to about 350 psig.

While other promoter materials such as potassium and sodium are known in the art, thorium is employed as a promoter for the cobalt metal component in the practice of the invention. The most effective level of promotion appears to be obtained when about 15% ThO_2 is employed based on the weight of cobalt metal employed. The concentration of thorium can vary, however, from about 0.1 to about 15%, and some of the ThO_2 can be replaced with less expensive MgO provided that at least about 5% ThO_2 is retained for the desired

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promoter activity in preferred embodiments of the invention.

Prior to use of the Fischer-Tropsch catalyst composition in the syngas conversion process of the invention, the cobalt catalyst is reduced or activated by techniques employing hydrogen alone or together with other treating materials as is known in the art. For example, the catalyst may be activated by first combining with a low H_2/CO ratio gas, or with CO alone, at a temperature in the range of about 250-320°C and a pressure of from 0 psig to the synthesis gas pressure. The catalyst is then further treated with hydrogen under similar temperature and pressure conditions. Further information regarding the preparation and activation of Fischer-Tropsch catalysts is provided in the published art, as in CATAL, REV.-SCI. ENG. 21(2), 225-274 (1980), "The Fischer-Tropsch Synthesis in the Liquid Phase", by Herbert Kolbel and Miles Ralek, particularly pp. 242-247 thereof.

In preferred embodiments of the invention, the Fischer-Tropsch catalyst composition desirably includes a support additive for said thorium-promoted cobalt and additive component admixture. In particularly preferred embodiments, said support component comprises a molecular sieve co-catalyst/support component rather than an inert support component such as α -alumina. The presence of such a co-catalyst material facilitates the desired conversion of syngas to liquid motor fuels. An especially desirable co-catalyst/support

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component for purposes of the invention comprises steam-stabilized, hydrophobic zeolite Y catalyst, sometimes referred to in the art as ultrahydrophobic type Y zeolites, or simply as UHP-Y zeolites. The cobalt, with or without thorium promotion, and the additive component may be positioned mainly in the large pores between the crystallites formed during the extrusion of the catalyst. It has also been found possible to place said cobalt and said additive component substantially within the crystallites of said UHP-Y zeolite as further discussed below. The Y zeolites used in this invention are prepared by extensive steaming of the low-sodium forms of zeolite Y substantially as described in Belgian Patent No. 874,373, issued February 22, 1979. Such zeolites are organophilic zeolitic aluminosilicate compositions having a $\text{SiO}_2/\text{Al}_2\text{O}_3$ molar ratio equal to or greater than 4.5, and an essential X-ray powder diffraction pattern of zeolite Y. Furthermore, the zeolites have a crystallographic unit cell dimension, a_0 , of less than 24.45 Angstroms, a sorptive capacity for water vapor at 25°C and a p/p_0 value of 0.10 of less than 10.0 weight percent. In preferred compositions, said unit cell dimension of the catalyst is from 24.20 to 24.35 Angstroms. In addition, the water adsorption capacity at 25°C and a p/p_0 value of 0.10 is desirably less than 6.0 or even 4.0 weight percent. More particularly, the $\text{SiO}_2/\text{Al}_2\text{O}_3$ molar ratio for certain embodiments is from 4.5 to 20.0. In a desirable embodiment in which the UHP-Y zeolite is acid extracted as

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discussed below, the $\text{SiO}_2/\text{Al}_2\text{O}_3$ molar ratio may be extended up to about 100 or more, as the alumina content of the zeolite is generally reduced to less than about 3 weight % or even to about 1 weight % or less in practical commercial applications.

For the determination of the sorptive capacity of the hydrophobic zeolite Y compositions for any particular adsorbate, e.g. water, the test zeolite sample is activated by preheating at 425°C for 16 hours at a pressure of 5 micrometers of mercury in a conventional McBain apparatus. The temperature of the sample is thereafter adjusted to the desired value and contacted with the vapor of the test adsorbate at the desired pressure.

The hydrophobic zeolites suitable for purposes of the invention, as described above, have also been found especially suited for use as adsorbents in applications where it is desired to preferentially adsorb organic constituents from solutions or mixtures thereof with water. In the formation of synthesis gas by the distillation of coal for example, it is desirable, for environmental and economic reasons, to recover the relatively small portion of phenol present in the condensate fraction of principally water that is produced therein. For this purpose, the condensate can be contacted at ambient temperature with said hydrophobic zeolite that will selectively adsorb the phenol from said condensate. Such zeolites have also been found highly suitable for use as base materials for catalyst compositions having important

commercial applications, e.g. in midbarrel hydrocracking catalyst compositions. The UHP-Y zeolites described in particular detail in the Belgian patent referred to above have been found
5 active for the conversion of methanol to hydrocarbons ranging from methane to those boiling in the jet fuel and diesel oil boiling range up to about C₂₂ material.

The invention is hereinafter described with
10 reference to specific comparative tests that are presented to illustrate the invention and the advantages thereof. These illustrative comparative tests should not be construed, however, as limiting the scope of the invention as set forth in the
15 appended claims.

Example I

This example is presented as a comparative reference and is based on the conversion of syngas using a thorium-promoted cobalt catalyst supported
20 on a UHP-Y co-catalyst/support component without the admixture of an additive component with said cobalt as in the practice of the invention illustrated in Example II below. For purposes of this Example I, the cobalt metal component was prepared by
25 precipitation upon the addition of a 10% excess of sodium carbonate solution to a stirred room temperature aqueous solution of 400 g. of cobalt nitrate, i.e. Co(NO₃)₂•6H₂O. The cobalt
oxide precipitate was washed with hot water and
30 dried at 110°C overnight. It was then impregnated with a thorium nitrate solution to provide a 15 wt. % thorium concentration, based on the weight of

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cobalt, on the precipitate, which was then dried at 110°C.

This thorium-promoted cobalt metal component was formed as 1/8" silica bonded extrudate containing 15% CoO/ThO₂, 70% UHP-Y zeolite and 15% by wt. silica binder. The resulting extrudate was dried at 110°C for two hours.

80cc of this catalyst was loaded into an internal recirculation reactor, in which it was treated, for cobalt activation, with hydrogen, at 300 psig, from room temperature up to 350°C, where it was held for 24 hours before cooling to 270°C for treatment with 1:1 syngas. The syngas was fed to the reactor at a rate of 400 cc/min or 300 GHSV, i.e. gas hourly space velocity, or volume of gas (at 0°C, 1 atm)/volume catalyst/hour. The conversion reaction was carried out at a pressure of about 300 psig and at a temperature of about 270°C. The results obtained in terms of the conversion of syngas, the primary product selectivity between hydrocarbons and CO₂, the hydrocarbon selectivity to the desirable C₅⁺ range and other pertinent product characterizations are as set forth below, including Table I, under the various operating conditions recited in the Table.

TABLE I

<u>Run</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Hours on Stream	19.5	115.5	139.5	163.5	187.5
Temperature, °C	272	269	269	270	269
5 Feed, cc/min.	400	400	400	400	400
Conversion, wt. %					
on CO	62.86	44.21	39.12	40.43	38.31
on H ₂	89.40	72.07	66.43	67.26	65.97
on (CO+H ₂)	75.66	58.36	52.78	53.81	52.12
10 Product Selectivity, wt. %					
CH ₄	14.67	19.66	23.12	22.63	24.15
C ₂ -C ₄	13.23	12.86	15.47	13.70	14.59
C ₅ -420°F	50.41	42.22	38.71	41.04	39.90
420-700°F	19.19	20.35	16.74	16.65	15.78
15 700°F-end point	2.51	4.91	5.95	5.98	5.58
C ₅ -end point	72.10	67.48	61.41	63.67	61.26
Iso/Normal Mole Ratio					
C ₄	0.2857	0.1226	0.1778	0.1370	0.1327
C ₅	0.5572	0.2546	0.2698	0.2540	0.2473
20 C ₆	0.9660	0.4117	0.4181	0.4006	0.3892
Paraffin/Olefin Ratio					
C ₃	0.6912	1.4156	1.1943	1.2831	1.2776
C ₄	0.4206	0.7010	0.7044	0.6503	0.6289
25 C ₅	0.5004	0.7141	0.6954	0.6438	0.6146

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Those skilled in the art will appreciate that the gasoline end point is about 420°F, while the diesel oil end point is about 200°F. It will also be appreciated that the 420-700°F hydrocarbon material comprises molecules with more carbon atoms than C₁₀ hydrocarbons up to about C₂₂ material. Hydrocarbon material in the C₂₂-C₂₈ range generally comprises heavy distillate material, with material above C₂₈ generally comprising wax.

The catalyst of this example showed an initial deactivation and an increase in methane production. The selectivity to condensed products was high, but the condensed products obtained contained undesired solids therein. The total condensed product was distilled and fractionated into gasoline (initial boiling point -420°F), jet fuel (300-550°F) and diesel oil (300-700°F) fractions. The gasoline fraction contained 36.4% olefins upon FIA, i.e., Florescence Indicator Absorption analysis. Under such analysis, the jet fraction contained 31.6% olefins and had a pour point of 0°F. It will be appreciated that the pour point is the lowest temperature at which the liquid will flow. The diesel fraction had a pour point of 50°F. With such a high pour point, the diesel oil fraction could not be pipelined at low temperature.

Example II

In this comparative example illustrating the practice of the invention, the adsorbent composition was prepared as in Example I above, except that the thorium - promoted cobalt component was impregnated with a solution of ammonium

5 heptamolybdate to provide a 15% by weight deposition of molybdenum on the CoO/ThO_2 component. The thus-impregnated Fischer-Tropsch metal component was dried and formulated into an extruded catalyst as in said Example I. The catalyst loading, pretreatment and testing for syngas conversion were also essentially as set forth in Example I. The results obtained are set forth in Table II below:

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TABLE II

<u>Run</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
Hours on Stream	17.0	74.0	122.0	146.0	185.0
Temperature, °C	270	269	270	270	270
5 Feed, cc/min.	400	400	400	400	400
Conversion, wt. %					
on CO	67.21	55.09	51.71	51.48	49.81
on H ₂	82.61	77.73	75.32	75.35	74.06
on (CO+H ₂)	75.19	66.84	63.93	63.82	62.42
10 Product Selectivity					
CH ₄	14.00	17.04	18.34	18.20	19.99
C ₂ -C ₄	16.08	18.20	18.89	18.51	19.21
C ₅ -420°F	50.88	48.12	48.39	48.01	46.34
420°F-700°F	16.31	14.33	12.41	13.20	12.45
15 700°F-end point	2.73	2.31	1.97	2.07	2.01
C ₅ -end point	69.92	64.76	62.77	63.29	60.80
Iso/Normal Mole Ratio					
C ₄	0.2051	0.1383	0.1154	0.1083	0.0963
C ₅	0.4293	0.2618	0.2199	0.2101	0.1680
20 C ₆	0.8211	0.4066	0.3208	0.2929	0.2642
Paraffin/Olefin Ratio					
C ₃	1.1915	0.9740	0.9481	0.9506	0.9195
C ₄	0.6064	0.4851	0.4752	0.4787	0.4719
C ₅	0.7138	0.5197	0.4852	0.4779	0.4687

TABLE II (continued)

<u>Run</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>
Hours on Stream	215	258.5	307.5	354.8	426.0
Temperature, °C	270	270	269	269	269
5 Feed, cc/min.	400	400	400	400	400
Conversion, wt. %					
on CO	48.82	48.47	44.98	43.85	42.02
on H ₂	73.00	72.46	69.44	68.54	67.52
on (CO+H ₂)	61.41	60.98	57.65	56.63	55.20
10 Product Selectivity					
CH ₄	20.41	20.34	21.47	22.74	24.00
C ₂ -C ₄	19.61	19.13	21.41	21.88	22.57
C ₅ -420°F	46.61	47.62	45.44	43.74	42.56
420-700°F	11.45	11.01	9.89	9.93	9.30
15 700°F-end point	1.92	1.90	1.79	1.70	1.57
C ₅ -end point	59.98	60.53	57.12	55.38	53.43
Iso/Normal Mole Ratio					
C ₄	0.1000	0.0914	0.0448	0.0815	0.0771
C ₅	0.1634	0.1573	0.1414	0.1522	0.1412
20 C ₆	0.2527	0.2294	0.2181	0.2079	0.1174
Paraffin/Olefin Ratio					
C ₃	0.9303	0.9297	0.9590	0.9077	0.8321
C ₄	0.4615	0.4685	0.4617	0.4648	0.4650
C ₅	0.4648	0.4672	0.4665	0.4918	0.5468

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It will be seen from the results of Example II as compared with those of Example I, the catalyst of the invention did not show the rapid initial deactivation and increase in methane selectivity seen in the use of the reference catalyst of Example I. The C₄ hydrocarbons will be seen to be much more olefinic than in Example I, and the paraffin/olefin ratio in the Example II runs tends to decline appreciably and then remain relatively constant over the course of a relatively long period of on stream performance, whereas the ratio tends to increase appreciably and then to level off in the reference runs of Example I. The condensed liquid samples of Example II were combined and distilled into gasoline, jet and diesel oil fractions as in Example I. The gasoline fraction contained 48.3% olefins and the jet fraction contained 43.6% olefins, both significantly higher amounts than were obtained in the reference runs of Example I. The pour point of the jet fraction is -10°F, and that of the diesel oil is 20°F, again representing significant improvements as compared to the reference runs. It will thus be appreciated that the process and catalyst composition of the invention provide a convenient and effective means for achieving the objects stated above, namely the improving of syngas conversion operations by enhancing the olefinic content of the liquid hydrocarbon conversion products obtained. The significant advantages obtained by the practice of the invention with respect to the olefinic content of the liquid products is further enhanced when the

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Fischer-Tropsch catalyst composition contains a molecular sieve material therein, as in the comparative examples, since the molecular sieve can act upon olefins much easier than it can act upon paraffins for the production of more desirable liquid motor fuel materials.

Those skilled in the art will appreciate that various changes and modifications can be made in the details of the invention without departing from the scope of the invention as set forth in the appended claims. Thus, as noted above, the desired enhancement of the olefinic content of the liquid hydrocarbon products can be facilitated by the use of a modified UHP-Y co-catalyst/support component or by the use of other such desirable support components. For example, the UHP-Y zeolite referred to above can be employed in aluminum-extracted form. Furthermore, the cobalt and said additive component can be positioned substantially within the crystallites of the UHP-Y zeolite or of the aluminum-extracted form thereof, and not merely within the large pores between the crystallites formed during extrusion of the catalyst, thus enhancing catalyst stability. In general when a co-catalyst/support is employed, the cobalt metal component will be employed in an amount within the range of from about 1% to about 25% by weight based on the overall weight of the catalyst composition, with cobalt concentrations of from about 5% to about 15% being generally preferred for most applications. When a co-catalyst/support component is not employed, from about 1% to about 100% cobalt

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by weight is useful, based on the total weight of cobalt, inert metal and possibly other additives, with about 5% to about 50% cobalt being preferred.

For purposes of achieving the

5 aluminum-extracted form of said UHP-Y zeolite, the zeolite is conveniently acid washed or extracted essentially by the process as described in the Eberly patent, U.S. 3,591,488, to remove a large

10 portion of the alumina from its pores prior to treatment to incorporate the metal component therein. By employing a suitable cobalt-containing liquid, such as cobalt carbonyl or a solution of cobalt nitrate or other cobalt salt, the metal can

15 be positioned substantially within the crystals, and absorbed therein to form a very stable co-catalyst/support composition highly advantageous for the purposes of the invention. In an illustrative example, UHP-Y molecular sieve zeolite was refluxed in a 13% slurry of said sieve in 3.75M

20 hydrochloric acid for three hours. The slurry was then cooled, and the supernatant was decanted therefrom. The remaining slurry was diluted in half, filtered and washed chloride free with 0.001 of nitric acid. The slurry was then washed with

25 distilled water, dried at 110°C for 16 hours and then at 250°C for 16 hours and at 500°C for an additional two hours and bottled at 400°C. The thus-treated material comprised acid-extracted, substantially alumina-free, or aluminum-extracted,

30 UHP-Y zeolite.

In preparing the catalyst composition of the invention in embodiments including a

co-catalyst/support component, the cobalt metal component, promoted and admixed with said additive component, can be physically mixed with the co-catalyst/support component, as in the examples
5 above, or can be precipitated on or pore filled on said co-catalyst/support component. For purposes of positioning the cobalt within the crystals of UHP-Y zeolite or the aluminum-extracted form thereof, a suitable cobalt solution can be loaded onto the
10 zeolite by impregnation followed by heating or treatment with base. Addition of the inert metal and/or the thorium can be accomplished either during cobalt impregnation or separately thereafter.

Another advantageous co-catalyst/support
15 component for purposes of the invention is a crystalline, microporous SAPO silicoaluminophosphate, non-zeolitic molecular sieve catalyst. Such catalyst materials, known as SAPOs and available at Union Carbide Corporation, are
20 described in U.S. Patent No. 4,440,871, issued April 3, 1984, incorporated in its entirety herein. Individual members of the SAPO class are designated as SAPO-5, SAPO-11, SAPO-17, SAPO-20, SAPO-31, SAPO-34 and the like as disclosed in said patent.
25 SAPO-11 and SAPO-31 are generally preferred for purposes of the invention, although it will be appreciated that other SAPOs, or combinations thereof alone or with other molecular sieves, may also be employed. It is, for example, within the
30 scope of the invention to employ a steam-stabilized, hydrophobic zeolite Y, i.e. UHP-Y, as an additional co-catalyst/support component in addition to said

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SAPO material. In particular embodiments, the cobalt and said additive component admixed therewith are positioned inside said zeolite Y component, as for example inside the crystallites of the aluminum-extracted form thereof, with the thus-loaded UHP-Y co-catalyst/support component being used together with said SAPO or other suitable co-catalyst/support component.

It will be appreciated that such specific embodiments are intended to achieve the desired increase in the olefinic content of the liquid products obtained upon syngas conversion employing catalyst compositions of desirable stability and catalytic activity favorable to the production of the desired liquid motor fuels. In such specific embodiments and more generally, the invention utilizes a modification of cobalt not previously appreciated, in the context of syngas conversion and of the need for increasing the olefinic content of the products obtained, as providing the desired advance in the production of motor fuels from such syngas. The invention thus enables the hydrocarbon products of the Fischer-Tropsch syngas conversion reaction to be more olefinic than they would otherwise be using the Fischer-Tropsch catalyst as employed, but without the addition of molybdenum or tungsten as an additive component. The invention thus represents a desirable advance in the art, enhancing the production of liquid motor fuels from syngas in an advantageous manner in light of the continuing need to meet the motor fuel requirements of industrial societies throughout the world.

CLAIMS

1. A process for the enhanced catalytic conversion of synthesis gas comprising carbon monoxide and hydrogen to C_5^+ hydrocarbon mixtures advantageous for use as liquid motor fuels comprising contacting said synthesis gas with a Fischer-Tropsch catalyst composition comprising cobalt, with or without thorium promotion, admixed with an additive component taken from the group consisting of molybdenum, tungsten and combinations thereof, said additive component being present in an amount within the range of from about 1% to about 50 mole % based on the total amount of cobalt and said additive component in said composition, whereby the presence of said additive component increases the olefinic content of the hydrocarbon products obtained, thereby enhancing the suitability of the resulting liquid hydrocarbons for use as motor fuels.

2. The process of Claim 1 in which the concentration of said additive component is from about 5% to about 25%.

3. The process of Claim 1 in which said synthesis gas conversion is carried out at a reaction temperature of from about 150°C to about 400°C.

4. The process of Claim 3 in which said reaction temperature is from about 240°C to about 320°C.

5. The process of Claim 1 in which said additive component comprises molybdenum.

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6. The process of Claim 1 in which said additive component comprises tungsten.

7. The process of Claim 1 in which said additive component comprises a combination of molybdenum and tungsten.

8. The process of Claim 5 in which the concentration of said molybdenum is from about 5 to about 25%, said conversion reaction temperature being from about 150°C to about 400°C.

9. The process of Claim 8 in which said reaction temperature is from about 240°C to about 320°C.

10. The process of Claim 1 in which said Fischer-Tropsch catalyst composition includes a support component for said cobalt and said additive component.

11. The process of Claim 10 in which said support component comprises a molecular sieve co-catalyst/support component.

12. The process of Claim 11 in which said co-catalyst/support component comprises a steam-stabilized, hydrophobic zeolite Y catalyst.

13. The process of Claim 12 in which said additive component comprises molybdenum.

14. The process of Claim 12 in which said co-catalyst/support component comprises said zeolite Y in aluminum-extracted form, said cobalt and said

additive component being positioned substantially within the crystallites of said aluminum-extracted zeolite.

15. The process of Claim 14 in which said additive component comprises molybdenum and said conversion reaction temperature is from about 150°C to about 400°C.

16. The process of Claim 15 in which said reaction temperature is from about 240°C to about 320°C.

17. The process of Claim 11 in which said co-catalyst/support component comprises a crystalline, microporous SAPO silicalumino-phosphate, non-zeolitic molecular sieve catalyst.

18. The process of Claim 17 in which said SAPO catalyst comprises SAPO-11.

19. The process of Claim 17 in which said SAPO catalyst comprises SAPO-31.

20. The process of Claim 17 in which said additive component comprises molybdenum.

21. The process of Claim 17 in which said additive component comprises tungsten.

22. The process of Claim 17 and including a steam-stabilized, hydrophobic zeolite Y additional co-catalyst/support component.

23. The process of Claim 22 in which said SAPO catalyst comprises SAPO-11.

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24. The process of Claim 23 in which said zeolite Y component is in aluminum-extracted form.

25. The process of Claim 24 in which the alumina content of said aluminum-extracted zeolite is less than about 3 weight %.

26. The process of Claim 25 in which the concentration of said additive component is from about 5% to about 25% and said conversion reaction temperature is from about 150°C to about 400°C.

27. The process of Claim 26 in which said additive component comprises molybdenum.

28. The process of Claim 1 in which said cobalt is promoted with thorium.

29. The process of Claim 8 in which said cobalt is promoted with thorium.

30. The process of Claim 11 in which said cobalt is promoted with thorium.

31. A synthesis gas conversion catalyst composition adapted for the enhanced catalytic conversion of synthesis gas comprising carbon monoxide and hydrogen to C_5^+ hydrocarbon mixtures advantageous for use as liquid motor fuels comprising:

(a) a Fischer-Tropsch catalyst component comprising cobalt, with or without thorium promotion; and

(b) an additive component taken from the group consisting of molybdenum, tungsten and

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combinations thereof, said additive component being present in an amount within the range of from about 1% to about 50 mole % based on the total amount of cobalt and said additive component in said composition, whereby the olefinic content of the hydrocarbon products obtained is increased by the presence of said additive component, thereby enhancing the suitability of the resulting liquid hydrocarbons for use as motor fuels.

32. The composition of Claim 31 in which said additive component comprises molybdenum.

33. The composition of Claim 31 in which said additive component comprises tungsten.

34. The composition of Claim 31 in which the concentration of said additive component is from about 5% to about 25%.

35. The composition of Claim 31 in which said additive component comprises a combination of molybdenum and tungsten.

36. The composition of Claim 31 in which the concentration of said additive component is from about 5% to about 25%.

37. The composition of Claim 31 and including a support component for said cobalt and said additive component.

38. The composition of Claim 37 in which said support component comprises a molecular sieve co-catalyst/support component.

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39. The composition of Claim 38 in which said co-catalyst/support component comprises a steam-stabilized, hydrophobic zeolite Y catalyst.

40. The composition of Claim 39 in which said additive component comprises molybdenum.

41. The composition of Claim 39 in which said co-catalyst/support component comprises said zeolite Y in aluminum-extracted form, said cobalt and said additive component being positioned substantially within the crystallites of said aluminum-extracted zeolite.

42. The composition of Claim 41 in which said additive component comprises molybdenum.

43. The composition of Claim 41 in which said additive component comprises tungsten.

44. The composition of Claim 38 in which said co-catalyst/support component comprises a crystalline, microporous SAPO silicoaluminophosphate, non-zeolite molecular sieve catalyst.

45. The composition of Claim 44 in which said SAPO catalyst comprises SAPO-11.

46. The composition of Claim 44 in which said SAPO catalyst comprises SAPO-31.

47. The composition of Claim 44 in which said additive component comprises molybdenum.

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48. The composition of Claim 44 in which said additive component comprises tungsten.

49. The composition of Claim 44 and including a steam-stabilized, hydrophobic zeolite Y additional co-catalyst/support component.

50. The composition of Claim 49 in which said zeolite Y component is in aluminum-extracted form said cobalt and said additive component being positioned substantially within the crystallites of said aluminum-extracted zeolite.

51. The composition of Claim 50 in which the alumina content of said aluminum-extracted zeolite is less than about 3 weight %.

52. The composition of Claim 49 in which the concentration of said additive component is from about 5% to about 25%.

53. The composition of Claim 51 in which said additive component comprises molybdenum.

54. The composition of Claim 31 in which said cobalt is thorium-promoted cobalt.

55. The composition of claim 39 in which said cobalt is thorium-promoted cobalt.

56. The composition of Claim 41 in which said cobalt is thorium-promoted cobalt.

57. The composition of Claim 50 in which said cobalt is thorium-promoted cobalt.

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 85/01207

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶ According to International Patent Classification (IPC) or to both National Classification and IPC ⁴ C 07 C 1/04; B 01 J 23/85; B 01 J 23/88; B 01 J 29/04; IPC: B 01 J 29/16														
II. FIELDS SEARCHED Minimum Documentation Searched ⁷ <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%; border-bottom: 1px solid black;">Classification System</td> <td style="border-bottom: 1px solid black;">Classification Symbols</td> </tr> <tr> <td style="padding: 5px;">IPC ⁴</td> <td style="padding: 5px;">C 07 C 1/00 B 01 J 23/00; B 01 J 29/00</td> </tr> </table> Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸			Classification System	Classification Symbols	IPC ⁴	C 07 C 1/00 B 01 J 23/00; B 01 J 29/00								
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III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹ <table style="width: 100%; border-collapse: collapse;"> <tr> <th style="width: 10%; border-bottom: 1px solid black;">Category ⁹</th> <th style="width: 70%; border-bottom: 1px solid black;">Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²</th> <th style="width: 20%; border-bottom: 1px solid black;">Relevant to Claim No. ¹³</th> </tr> <tr> <td style="vertical-align: top; padding: 5px;">A</td> <td style="vertical-align: top; padding: 5px;">US, A, 2244573 (G. ROBERTS) 3 June 1941</td> <td></td> </tr> <tr> <td style="vertical-align: top; padding: 5px;">A, PEP,</td> <td style="vertical-align: top; padding: 5px;">A, 0140365 (UNION CARBIDE CORPORATION) 8 May 1985</td> <td></td> </tr> <tr> <td colspan="3" style="text-align: center; padding: 20px 0;">-----</td> </tr> </table>			Category ⁹	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³	A	US, A, 2244573 (G. ROBERTS) 3 June 1941		A, PEP,	A, 0140365 (UNION CARBIDE CORPORATION) 8 May 1985		-----		
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A, PEP,	A, 0140365 (UNION CARBIDE CORPORATION) 8 May 1985													

⁹ Special categories of cited documents: ¹⁰ "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "Δ" document member of the same patent family														
IV. CERTIFICATION <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; border-bottom: 1px solid black;">Date of the Actual Completion of the International Search</td> <td style="width: 50%; border-bottom: 1px solid black;">Date of Mailing of this International Search Report</td> </tr> <tr> <td style="text-align: center; padding: 5px;">2nd October 1985</td> <td style="text-align: center; padding: 5px;">30 OCT 1985</td> </tr> <tr> <td style="border-bottom: 1px solid black;">International Searching Authority</td> <td style="border-bottom: 1px solid black;">Signature of Authorized Officer</td> </tr> <tr> <td style="text-align: center; padding: 5px;">EUROPEAN PATENT OFFICE</td> <td style="text-align: center; padding: 5px;"> G.L.M. Krutgenberg </td> </tr> </table>			Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	2nd October 1985	30 OCT 1985	International Searching Authority	Signature of Authorized Officer	EUROPEAN PATENT OFFICE	 G.L.M. Krutgenberg				
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International Searching Authority	Signature of Authorized Officer													
EUROPEAN PATENT OFFICE	 G.L.M. Krutgenberg													

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO.

PCT/US 85/01207 (SA 10176)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 21/10/85

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 2244573		None	
EP-A- 0140365	08/05/85	AU-A- 3488384	09/05/85