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Aromatic hydrocarbons are produced from a feedstock comprising ethane and/or propane and/or butane by the steps of:

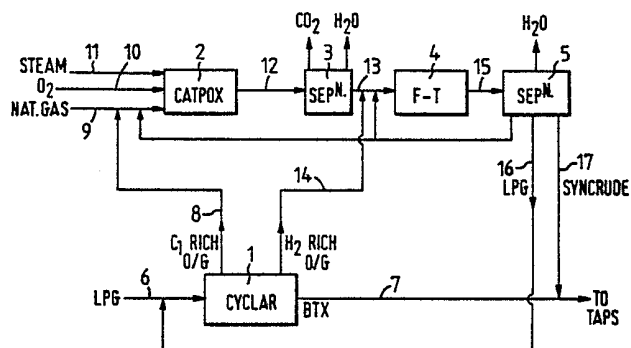
(A) reacting the feedstock in the presence of a dehydrocyclodimerisation catalyst to produce a product comprising aromatic hydrocarbons, hydrogen and methane,

(B) separating the product of step (A) into a aromatic hydrocarbon fraction, a methane-rich gaseous fraction and a hydrogen-rich gaseous fraction.

(C) feeding all or part of the methane-rich gaseous fraction separated in step (B) to a synthesis gas production unit, thereby to produce synthesis gas, and

(D) contacting the synthesis gas from step (C) together with all or part of the hydrogen-rich gaseous fraction separated in step (B), thereby increasing the hydrogen to carbon monoxide ratio of

the synthesis gas, with a Fischer-Tropsch conversion catalyst to produce a hydrocarbon product.



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PROCESS FOR THE PRODUCTION OF AROMATIC HYDROCARBONS INCORPORATING BY-PRODUCT UTILISATION

The present invention relates in general to the production of aromatic hydrocarbons and in particular to a process for the production of aromatic hydrocarbons by the catalysed conversion of a C₂-C₄ hydrocarbon feedstock in which by-products are utilised in the production of useful hydrocarbon products.

The catalysed production of aromatic hydrocarbons such as benzene, toluene and xylene by the catalysed conversion of a C₂-C₄ hydrocarbon feedstock, sometimes referred to as dehydrocyclodimerisation (DHCD), has been known for some time. One form of this process in which C₂-C₄ hydrocarbons are converted to aromatic hydrocarbons over a gallium loaded zeolite catalyst is rapidly gaining recognition as the BP Cyclar process. In addition to aromatic hydrocarbons the process generates, as by-products, a methane-rich stream and a hydrogen-rich stream, which in the absence of any other use for these products represent a loss to the process.

Although the C₂-C₄ hydrocarbon feedstock may be derived from other sources, for example by-product refinery streams, a potential source of such feedstock is Liquid Petroleum Gas (LPG) obtained by separating methane from natural gas, which though its detailed composition may vary according to its source, principally comprises methane, ethane, propane and butane together with minor amounts of one or more of carbon dioxide, nitrogen and C₄⁺ hydrocarbons. A potential use of the large volumes of recovered methane is as feedstock for conversion into synthesis gas by a variety of routes, followed by conversion of the synthesis gas so-produced into higher value products, such as for example methanol, higher alcohols, or hydrocarbons by the well-known Fischer-Tropsch (FT) conversion.

The production of hydrocarbons from methane or methane-containing mixtures, for example natural gas, by an initial conversion into synthesis gas by, for example, either steam reforming, autothermal reforming or partial oxidation, followed by conversion over a Fischer-Tropsch catalyst is by now recognised in the art. Whichever route is used for the generation of synthesis gas, it is generally necessary to adjust its hydrogen to carbon monoxide ratio to a value which is optimum for subsequent Fischer-Tropsch conversion into hydrocarbons. The oxidative routes, having a maximum hydrogen to carbon monoxide ratio of 2:1, require an increase in the hydrogen to carbon monoxide ratio. For this purpose a shift reaction involving the production of hydrogen by the reaction of steam

with a portion of the carbon monoxide generated by the synthesis gas production process is generally postulated. The shift reaction also produces carbon dioxide which is generally undesirable in the subsequent Fischer-Tropsch reaction and generally requires a step for its removal, together with carbon dioxide generated in the synthesis gas production step and steam. The inclusion of a shift reaction step and a possible carbon dioxide removal step detract from the economics of the process both in terms of capital expenditure in plant and loss of overall productivity through carbon loss.

We have now developed a process which integrates the two previously known processes in a manner which is mutually beneficial to their simultaneous operation.

Accordingly, the present invention provides a process for the production of aromatic hydrocarbons from a feedstock comprising ethane and/or propane and/or butane which process comprises the steps of:

(A) reacting the feedstock in the presence of a dehydrocyclodimerisation catalyst to produce a product comprising aromatic hydrocarbons, hydrogen and methane,

(B) separating the product of step (A) into an aromatic hydrocarbon fraction, a methane-rich gaseous fraction and a hydrogen-rich gaseous fraction,

(C) feeding all or part of the methane-rich gaseous fraction separated in step (B) to a synthesis gas production unit, thereby to produce synthesis gas, and

(D) contacting the synthesis gas from step (C) together with all or part of the hydrogen-rich gaseous fraction separated in step (B), thereby increasing the hydrogen to carbon monoxide ratio of the synthesis gas, with a Fischer-Tropsch conversion catalyst to produce a hydrocarbon product.

Preferably additional methane-containing hydrocarbon gas is fed to the synthesis gas production unit in step (C).

Advantages associated with the process of the invention are that by-product off-gas streams from the DHCD process can be fully utilised, the methane-rich gaseous fraction being used as feedstock to the synthesis gas production unit and the hydrogen-rich gaseous fraction being used to increase the hydrogen to carbon monoxide ratio of the synthesis gas to a value appropriate for F-T conversion, thereby either completely eliminating or considerably reducing the size of the synthesis gas shift operation and considerably reducing any carbon dioxide removal requirement.

In step (A) of the process of the invention there

may be used any suitable dehydrocyclodimerisation catalyst, though a gallium loaded ZSM-5 type aluminosilicate zeolite is preferred. The feedstock to this step may be either ethane, propane, butane, or a mixture thereof, which may also contain one or more of methane, ethylene, propylene or a higher olefin. A particularly suitable feedstock is the LPG separated from natural gas, typically by cryogenic means, methane recovered therefrom being a suitable feedstock to step (C) of the process. Typical process conditions, catalysts, catalyst treatments and other information pertinent to the operation of step (A) of the process may be found in our patent publications GB-A-1499199; 1561590 and 1537780 and EP-A-50021; 119027; 119023; 147111; 162636; 186949 and 202000 and pending unpublished European application No. 86306340.0, the disclosures of which are incorporated by reference herein.

The products of step (A) are aromatic hydrocarbons comprising a mixture of benzene, toluene and xylene (BTX), methane and hydrogen. In step (B) these products are separated into BTX, a methane-rich gaseous fraction and a hydrogen-rich gaseous fraction. This separation may be effected in conventional manner.

In step (C) all or part, preferably all, the methane-rich gaseous fraction separated in step (B) is fed, preferably together with additional methane-containing hydrocarbon gas, to a synthesis gas production unit. Suitably the methane-containing hydrocarbon gas may be any gas principally comprising methane, for example natural gas and/or the methane recovered from an LPG separation unit. It is preferred to use the methane separated from natural gas to provide LPG feedstock for step (A) of the process. The synthesis gas production unit may suitably be a steam reforming unit, an autothermal reforming unit or a partial oxidation unit, or a combination of primary steam reforming and secondary autothermal reforming, as described for example in our copending UK application publication No. 2179366 (BP Case No. 6046). Preferably the synthesis gas production unit is a partial oxidation unit because in contrast to steam reforming and/or autothermal reforming routes partial oxidation processes for the production of synthesis gas generally can not produce a synthesis gas having a hydrogen to carbon monoxide ratio greater than 2:1. The oxidative synthesis gas production unit may be either a catalysed or an uncatalysed partial oxidation unit, both of which are conventional in the art. A particularly suitable synthesis gas production unit is a catalytic partial oxidation unit which may take the form of a fluidised bed or a spouted bed of reforming catalyst to which is fed under appropriate conditions of temperature and pressure the aforesaid methane-containing feedstock, steam and an oxygen-containing gas, in suit-

able proportions. Suitably the oxygen-containing gas may be molecular oxygen, which may be diluted with an inert gas, for example nitrogen, suitably in proportions appreciably less than those pertaining in air. Preferred synthesis gas production units and methods for operating them are described in our copending European application publication Nos 163385, 164864 and 178853, the contents of which are incorporated by reference herein.

The synthesis gas produced in step (C) will generally contain, in addition to hydrogen and carbon monoxide, carbon dioxide either originating from the feedstock and/or formed in the synthesis gas production step, and possibly also steam. In an optional step (C') this carbon dioxide and water are removed in conventional manner, for example by solvent absorption, together with steam.

In step (D) the synthesis gas separated in step (C) is admixed with all or part of the hydrogen-rich gaseous fraction separated in step (B) for the purpose of increasing the hydrogen to carbon monoxide ratio thereof and contacted with an F-T conversion catalyst to produce a hydrocarbon product. The amount of hydrogen-rich gaseous fraction admixed is suitably sufficient to produce a hydrogen to carbon monoxide molar ratio greater than 2:1, preferably in the range from 2.05 to 2.2:1. In order to achieve this preferred range it may be necessary to either operate a hydrogen bleed or feed additional hydrogen, though in a preferred embodiment the total throughputs are adjusted to a value consistent with using the hydrogen-rich gaseous fraction without any adjustment of the hydrogen content thereof.

Suitable Fischer-Tropsch catalysts comprise one or more of the metals iron, cobalt or ruthenium, optionally supported on a suitable support, for example silica, alumina, titania or ceria. Suitably the catalyst may incorporate a crystalline zeolite, for example ZSM-5 or ultrastable zeolite Y. A preferred Fischer-Tropsch catalyst is one capable of converting synthesis gas to a mixture of gaseous C₂ to C₄ olefinic hydrocarbons and liquid C₅⁺ hydrocarbons. A particularly preferred catalyst is a ruthenium/ceria catalyst as described in our copending European application publication Nos. 0169743, 0211577 and 0232962, the disclosures of which are incorporated herein by reference. In an alternative embodiment, a preferred Fischer-Tropsch catalyst is one capable of converting synthesis gas to waxy hydrocarbons, which hydrocarbons are convertible to liquid C₅⁺ hydrocarbons by contact with a zeolite under appropriate conditions. A preferred catalyst of this type is cobalt, suitably in combination with a support, for example zinc oxide, as described in our copending European application No. 87308211.9, the disclosure of which is incorporated herein by reference.

Preferred Fischer-Tropsch catalysts are those which are tolerant to carbon dioxide, in which case step (C) may be eliminated or substantially reduced in size.

Thereafter it is preferred to separate the gaseous hydrocarbon fraction from the liquid hydrocarbon fraction of the F-T product and remove water therefrom. This may be accomplished by conventional means. Conveniently this separation may be combined with the separation of LPG from natural gas to provide the feedstock for step (A) of the process. The liquid C₅⁺ hydrocarbon fraction may suitably be used as a gasoline blending component.

In the event that the process is operated in proximity to a crude oil pipeline the BTX and liquid C₅⁺ hydrocarbon fraction may suitably be transported to the refinery via the crude oil pipeline.

A preferred embodiment of the invention will now be described with reference to the accompanying Figure which takes the form of a flowsheet.

With reference to the Figure, 1 is a dehydrocyclodimerisation reaction and separation unit, 2 is a catalytic partial oxidation unit, 3 is a carbon dioxide separation unit, 4 is a Fischer-Tropsch conversion unit, 5 is a Fischer-Tropsch product separation unit and 6 to 17 are transfer lines.

In operation LPG separated from natural gas, is fed through line 6 to the unit 1 wherein it is contacted with a DHCD catalyst to produce BTX, methane and hydrogen, which are separated into BTX, a methane-rich gaseous fraction and a hydrogen-rich gaseous fraction, the BTX being recovered through line 7. The gaseous methane-rich fraction is passed through line 8, combined with methane from the LPG separation and fed via line 9 to the catalytic partial oxidation unit, oxygen and steam being fed through lines 10 and 11 respectively. In the catalytic partial oxidation unit 2 the feedstock is converted to a product comprising carbon monoxide and hydrogen, together with carbon dioxide and steam. The product is fed through line 12 to the separation unit 3, wherein carbon dioxide and water are removed.

The hydrogen-rich gaseous fraction from the DHCD unit 2 is transferred via line 14 and admixed with the substantially carbon dioxide and water-free synthesis gas existing from the separation unit through line 13, thereby raising the hydrogen to carbon monoxide molar ratio of the synthesis gas to a value of about 2.14:1, before the mixture enters the Fischer-Tropsch conversion unit 4. In the F-T unit 4 the synthesis gas is converted to water and hydrocarbons comprising a mixture of gaseous C₂-C₄ hydrocarbons and liquid C₅⁺ hydrocarbons, which mixture is passed through line 15 to an F-T product separation unit 5, wherein the product is separated into water, LPG which is recycled

through line 16 to the LPG feed line 6, and a liquid C₅⁺ hydrocarbon fraction which is recovered through line 17. Although the F-T product separation unit 5 is shown as a separate unit in this case, it may be incorporated into the LPG from natural gas separation unit, thereby saving on plant.

It will be appreciated by those skilled in the art that the aforescribed process may be modified whilst still retaining the essential character of the invention. For example, in addition to or as an alternative to step (D) synthesis gas could be converted either into methanol or a mixture of higher alcohols.

Claims

1 A process for the production of aromatic hydrocarbons from a feedstock comprising ethane and/or propane and/or butane which process comprises the steps of:

(A) reacting the feedstock in the presence of a dehydrocyclodimerisation catalyst to produce a product comprising aromatic hydrocarbons, hydrogen and methane,

(B) separating the product of step (A) into an aromatic hydrocarbon fraction, a methane-rich gaseous fraction and a hydrogen-rich gaseous fraction.

(C) feeding all or part of the methane-rich gaseous fraction separated in step (B) to a synthesis gas production unit, thereby to produce synthesis gas, and

(D) contacting the synthesis gas from step (C) together with all or part of the hydrogen-rich gaseous fraction separated in step (B), thereby increasing the hydrogen to carbon monoxide ratio of the synthesis gas, with a Fischer-Tropsch conversion catalyst to produce a hydrocarbon product.

2 A process according to claim 1 wherein the synthesis gas production unit is an oxidative synthesis gas production unit.

3 A process according to either claim 1 or claim 2 wherein additional methane-containing hydrocarbon gas is fed to the synthesis gas production unit in step (C).

4 A process according to any one of the preceding claims wherein the feedstock reacted in step (A) is LPG separated from natural gas.

5 A process according to claim 4 wherein methane recovered from the separation of the LPG from natural gas is fed to step (C).

6 A process according to any one of the preceding claims wherein the dehydrocyclodimerisation catalyst of step (A) is a gallium loaded ZSM-5 type aluminosilicate zeolite.

7 A process according to any one of claims 2 to 6 wherein the oxidative synthesis gas production unit of step (C) is either a catalysed or uncatalysed partial oxidation unit.

8 A process according to claim 7 wherein the catalytic partial oxidation unit takes the form of either a fluidised bed or a spouted bed of reforming catalyst to which is fed under appropriate conditions of temperature and pressure the methane-containing feedstock, steam and an oxygen-containing gas. 5 10

9 A process according to any one of the preceding claims wherein carbon monoxide is produced in step (C) and in an additional step (C') carbon dioxide is removed from the synthesis gas. 15

10 A process according to any one of the preceding claims wherein the amount of hydrogen-rich gaseous fraction admixed with the synthesis gas in step (D) is sufficient to produce a hydrogen to carbon monoxide molar ratio greater than 2:1. 20

11 A process according to claim 10 wherein the hydrogen to carbon monoxide molar ratio is in the range from 2.05 to 2.2:1.

12 A process according to any one of the preceding claims wherein the Fischer-Tropsch catalyst is a catalyst capable of converting synthesis gas to a mixture of C₂ to C₄ olefinic hydrocarbons and liquid C₅⁺ hydrocarbons. 25

13 A process according to claim 12 wherein the Fischer-Tropsch catalyst comprises ruthenium and ceria. 30

14 A process according to any one of claims 1 to 11 wherein the Fischer-Tropsch catalyst is one capable of converting synthesis gas to waxy hydrocarbons. 35

15 A process according to claim 14 wherein the Fischer-Tropsch catalyst comprises cobalt and zinc oxide.

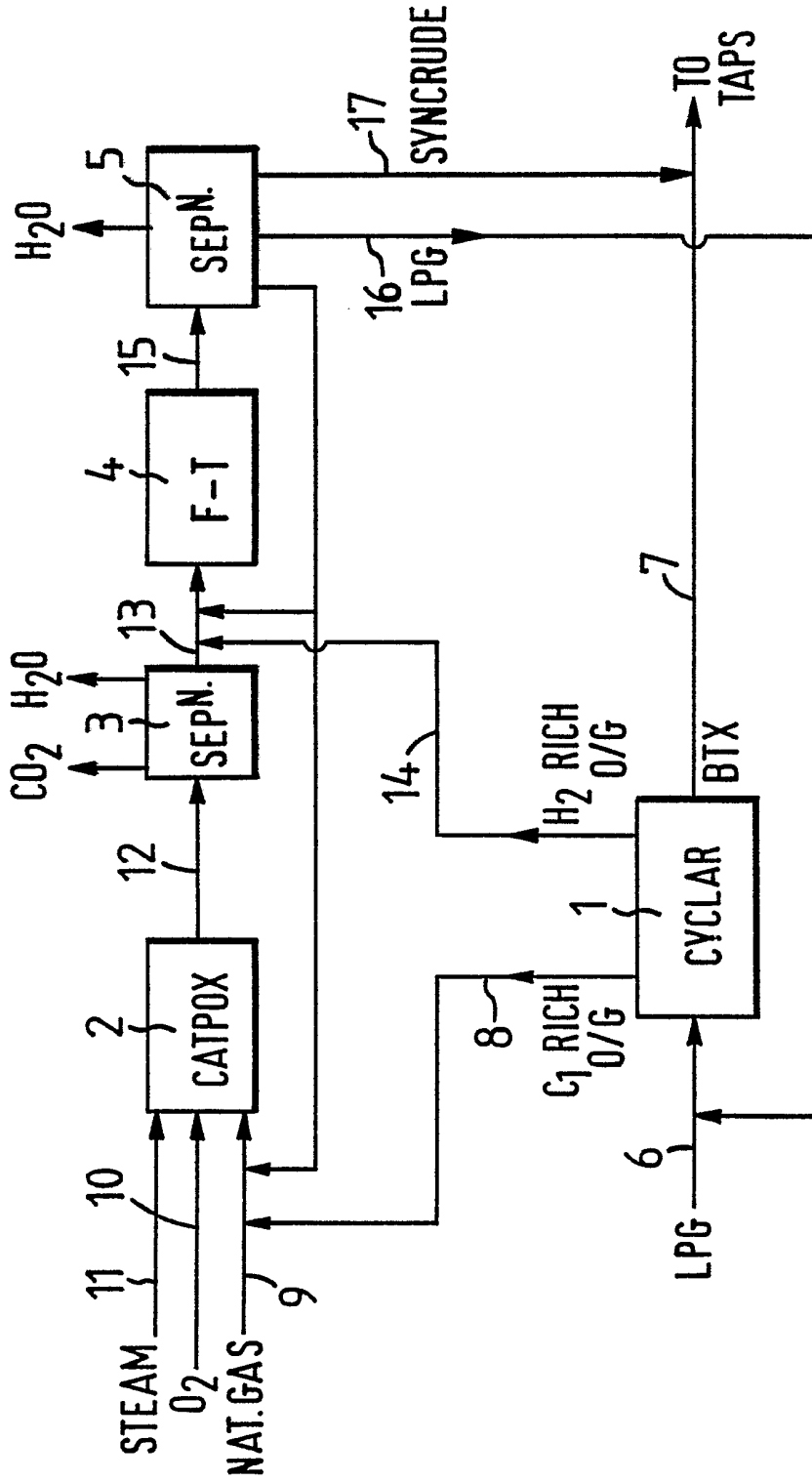
16 A process according to any one of claims 12 to 15 wherein the Fischer-Tropsch catalyst further incorporates a zeolite. 40

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| DOCUMENTS CONSIDERED TO BE RELEVANT | | | |
|---|---|--|---|
| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int. Cl.4) |
| D,X | EP-A-0 147 111 (B.P.) * Claims; page 2, lines 14-15 * --- | 6 | C 07 C 15/00 C 07 C 2/76 |
| D,X | EP-A-0 163 385 (B.P.) * Claims * --- | 7,8 | C 01 B 3/44 C 07 C 1/04 |
| D,X | EP-A-0 169 743 (B.P.) * Claims * --- | 13,16 | |
| X | CA-A-1 122 620 (SHELL) * Claims * --- | 1,15 | |
| P,X | US-A-4 677 235 (MOWRY) * Claims; column 5 * ----- | 6 | |
| | | | TECHNICAL FIELDS SEARCHED (Int. Cl.4) - |
| | | | C 07 C 15/00 C 07 C 1/00 C 07 C 2/00 |
| The present search report has been drawn up for all claims | | | |
| Place of search THE HAGUE | | Date of completion of the search 02-02-1988 | Examiner VAN GEYT J.J.A. |
| <p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons</p> <p>..... & : member of the same patent family, corresponding document</p> | | | |