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Aldridge

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[54] **TWO-STAGE PROCESS FOR THE CONVERSION OF LIQUID HYDROCARBON TO A METHANE RICH GAS STREAM**

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[*] Notice: The portion of the turn of this patent subsequent to June 11, 1991, has been disclaimed.

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[21] Appl. No.: **280,761**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 125,581, March 18, 1971, abandoned.

[52] **U.S. Cl.** ..... **48/214;** 48/197 R; 48/202; 48/206; 208/127

[51] **Int. Cl.** **C01b 2/14**

[58] **Field of Search** ..... 48/197 R, 214, 211, 202, 48/206; 208/108, 122, 53, 283, 284, 55, 50, 209; 252/476, 425, 444, 445, 446, 447; 423/652, 654, 657

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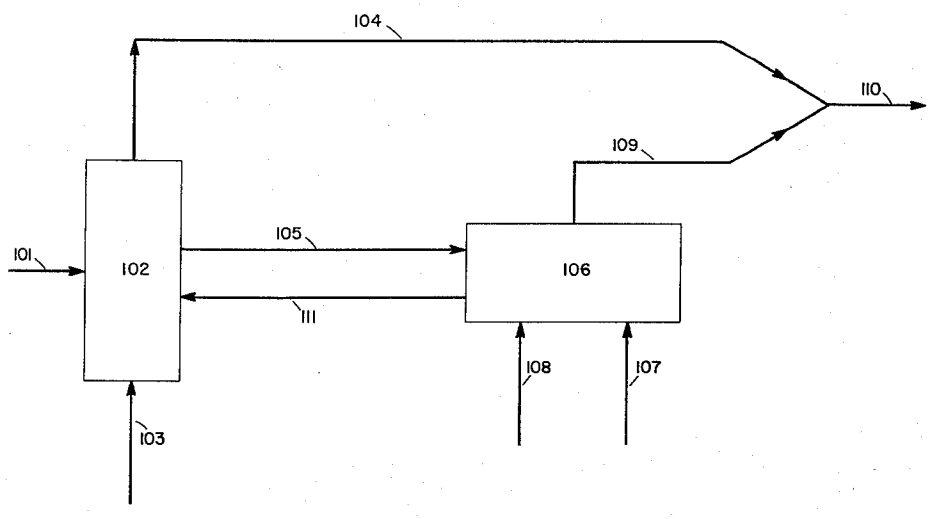
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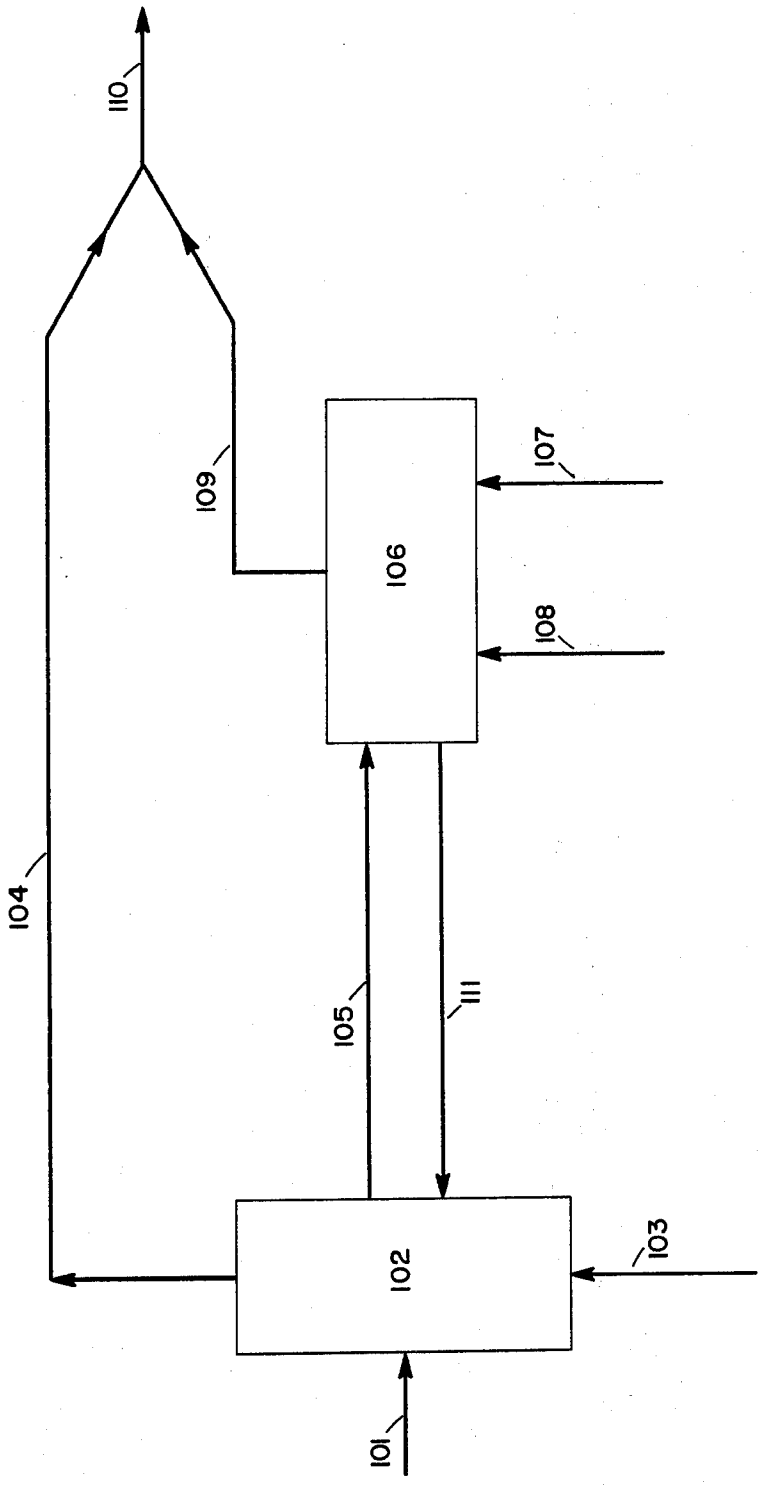
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[57] **ABSTRACT**

Liquid hydrocarbons are converted to a methane rich gas stream by contact with a non-molten particulate alkali metal composition in a two-stage process wherein each stage is operated at pressures above 200 psig and temperatures above 1,000°F. Solid hydrocarbon material deposits on the particulate composition in the 1st stage and is converted to a gaseous product by reaction with steam in the 2nd stage.

19 Claims, 1 Drawing Figure




110
109
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101

TWO-STAGE PROCESS FOR THE CONVERSION OF LIQUID HYDROCARBON TO A METHANE RICH GAS STREAM

RELATED APPLICATIONS

This application is a continuation-in-part of Ser. No. 125,581 by Clyde L. Aldridge filed Mar. 18, 1971, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to a two-stage process for the conversion of a liquid hydrocarbon to a methane rich stream in the presence of a particulate alkali metal composition.

The use of alkali metal compounds as catalysts in various hydrocarbon conversion processes is well known. For example, U.S. Pat. No. 2,893,941 discloses the use of a minute quantity (i.e. ppm) of K_2CO_3 in a steam cracking process to prohibit coke formation. It is also known (U.S. Pat. No. 3,112,257) that hydrocarbon oils can be desulfurized by contact with steam in the presence of a Group VI to VIII alkali metal catalyst system at temperatures under 900°F. Alkali metal compounds are also known to increase hydrogen production when steam gasifying solids carbonaceous material (see U.S. Pat. No. 3,252,773) and when coking hydrocarbon oils (see U.S. Pat. No. 3,179,584). As disclosed in U.S. Pat. No. 3,252,774, it is further known that liquid hydrocarbons can be converted to a hydrogen-rich gas stream by contact with steam and a large excess of molten alkali metal catalyst system at low feed rates.

It has now been found that increased benefits can be obtained by converting a liquid hydrocarbon to a methane rich stream in a two-stage process operated under specified conditions and employing a particulate catalyst composition comprising an alkali metal compound. With the two-stage process of the invention a greater yield of methane can be obtained than that which would be obtainable with a one-stage process. Furthermore, the two-stage process is more thermally efficient and requires less steam per given quantity of product gas than a one-stage process. Further benefits will become apparent from the ensuing description.

SUMMARY OF THE INVENTION

In accordance with the invention, a hydrocarbon feedstream containing a liquid hydrocarbon is converted to a methane rich stream by (a) treating said feedstream in a first reaction zone maintained at a pressure above 200 psig and at a temperature above 1,000°F., in the presence of a particulate catalyst composition comprising an alkali metal compound and a solid particulate material to produce a vaporous product comprising methane and other light hydrocarbon products, and a solid hydrocarbon material which deposits on said particulate catalyst composition; (b)removing said vaporous product from said first reaction zone; (c)passing at least a portion of said particulate catalyst composition with the solid hydrocarbon material deposition to a second reaction zone maintained at a pressure above 200 psig and a temperature above 1,000°F. to contact steam introduced into said second reaction zone whereby at least a portion of said solid hydrocarbon material deposition is converted to a gaseous product comprising CH_4, H_2, CO_2, and CO, and (d)removing the gaseous product from said reaction zone. Preferably the gaseous product of step (d) is

combined with the vaporous product of step (b) to produce a combined stream rich in methane content, and the resulting methane rich stream is recovered.

In one embodiment, the vaporous product of step (b), is treated to remove some components such as normally liquid hydrocarbons which may be present therein, prior to combining the remaining vaporous product with at least a portion of the gaseous product of step (d). In another embodiment, the gaseous product of step (d) is treated to remove unreacted steam and/or CO_2 prior to combining the remaining gaseous product with at least a portion of the vaporous product of step (b).

In another embodiment, the normally liquid hydrocarbon products separated from the vaporous product of the first reaction zone or from the combined stream are recycled to the first reaction zone or to the second reaction zone.

In another embodiment of the invention, an oxygen containing gas such as air or oxygen may also be introduced into the first reaction zone or into the second reaction zone or into both zones. Furthermore, when it is desired to maintain the catalyst composition in the first reaction zone fluidized, a fluidizing gas such as steam or a recycled product gas may be introduced into the first reaction zone.

BRIEF DESCRIPTION OF THE DRAWING

The accompanying drawing is a diagrammatic flow plan of a preferred embodiment of the two-stage process of this invention.

PREFERRED EMBODIMENTS OF THE INVENTION

The preferred embodiments of the invention will be described with reference to the accompanying drawing.

The process of this invention is applicable to a great variety of hydrocarbon feedstreams which are liquid or contain a liquid hydrocarbon. By liquid hydrocarbon is intended to mean a hydrocarbon or mixture of hydrocarbons having an atmospheric boiling point greater than 100°F. and which is fluid, that is, either in vapor phase or in liquid phase, at temperatures in the range of 75°F. to 900°F. and at atmospheric pressure. Suitable hydrocarbon feedstreams would include naturally occurring petroleum oils, refined fractions thereof, as well as individual hydrocarbons. Therefore, by way of example, the feedstream may include a single normally liquid hydrocarbon including acyclic and alicyclic hydrocarbons and aromatics such as hexanes, heptanes, cyclohexane, benzene, toluene, xylenes, naphthalene and mixtures thereof. The process can also be used for the conversion of various normally liquid or liquid containing petroleum fractions from light to heavy oils and tars. Typical examples of such fractions are gas oils including straight run gas oil (boiling range of between about 400°F. and about 800°F.), thermally cracked gas oils and heavy gas oil, cycle oils such as fluid catalytically cracked cycle oil, light naphtha (boiling range from about 100°F. to about 250°F.), heavy naphtha (boiling range from about 200°F. to about 400°F.), straight run gasoline, kerosene, diesel oil, whole crude and residual fractions such as a reduced crude and vacuum residuum. The term "reduced crude" as used herein is intended to mean a crude oil from which the light materials and gasoline boiling range constituents have been removed and which has been distilled to re-

move the gas oils present therein. The initial boiling point of such an oil is usually between about 500°F. and about 800°F. although this may vary somewhat. The process of this invention is also applicable to the conversion of shale oil, tar sand oil, asphalt tar and other liquid-containing heavy viscous material, including petroleum wax fractions. Furthermore, the process of this invention is applicable to a hydrocarbon feedstream which is a fluid mixture of liquid or liquid containing hydrocarbons having suspended therein a solid hydrocarbon material such as coke or coal. This process is particularly suited to handle feedstreams that contain more than 10 wt. % liquid hydrocarbon having a boiling point greater than about 430°F. It is especially suited to handle feedstreams which contain more than 10 wt.% liquid hydrocarbon having a boiling point greater than about 900°F.

Referring to the drawing, a hydrocarbon feedstream containing a liquid hydrocarbon is introduced by line **101** into a first reaction zone **102** to contact a non-molten particulate alkali metal catalyst composition. A fluidizing gas such as steam is introduced into reaction zone **102** by line **103.** If desired an oxygen-containing gas such as air or oxygen may also be introduced with the steam. The hydrocarbon may be mixed with the catalyst composition in the first reaction zone prior to introducing steam into the zone.

While the first reaction zone can be a fixed, moving or fluid bed, the latter two would be preferred for feedstreams containing the heavier liquid hydrocarbons. Because of the ease in maintaining uniform temperature distribution and the prevention of large coke conglomerate formation, the fluid bed would be particularly preferred especially for feedstreams containing large amounts of liquid hydrocarbons having a 900°F.+ boiling point.

The catalyst composition comprises an alkali metal compound and a solid particulate material as carrier or support. Suitable alkali metal compounds would include the carbonates, acetates, formates, oxides and hydroxides of sodium, lithium, cesium and potassium. The alkali metal compound may be deposited on the solid particulate material or it may be mixed with the solid particulate material. The solid particulate material may be catalytic in nature or inert and it may be porous or not porous. Suitable solid particulate material would include any of the well-known cracking catalysts such as zeolites, silica-alumina, zirconia, gamma alumina, crude or partially purified bauxite, and the like or a more catalytically inert material such as alpha alumina, alundum, mullite, silica, synthetically prepared or naturally occurring material, such as, pumice, clay, diatomaceous earth (kieselguhr); porcelain, glass or marble spheres or other inert spherical materials. Suitable solid particulate material also includes coke and activated carbon. A preferred catalyst composition would include K_2CO_3 or Cs_2CO_3 mixed with alumina, silica-alumina, crude or partially purified bauxite or mixtures thereof.

Furthermore, it has been found that when the solid particulate material has a carbon coating and an alkali metal maintained on it, an unexpected amount of additional cracking occurs. Such a catalyst composition can be obtained by mixing an alkali metal compound such as those named above with the solid material in the first reaction zone under the given operating conditions. A liquid containing hydrocarbon feed is then introduced into the first reaction zone and a portion of the feed is laid down on the solid material as carbon. While applicant does not wish to be bound by theory, it is believed that the alkali metal then attaches itself to the carbon laid on the solid material to form the desired catalyst system.

The first reaction zone is maintained at a pressure above 200 psig, preferably a pressure between about 250 and 1,500 psig, more preferably at pressures between about 400 and 1,000 psig and at a temperature above 1,000°F., preferably at temperatures between about 1,000° and 1,600°F., more preferably between about 1100° and 1,500°F., most preferably between about 1,200° and 1,450°F.

The rate at which the liquid containing hydrocarbon is fed into the first reaction zone will depend in part upon the operating conditions within that zone. Under the above given operating conditions, feed rates between 0.02 and 2.00 or higher W feed/W catalyst composition bed/Hr. and preferably between 0.05 and 1.5 W feed/W catalyst composition bed/Hr. and most preferably between 0.1 and 1.0 W feed/W catalyst composition bed/Hr. may be employed. Under the above operating conditions and feed rates, the weight % of alkali metal in the bed will range broadly between 0.5 and 35 wt. %, preferably between 2 and 25 wt. %, more preferably between 4 and 15 wt. %.

Steam is introduced in an amount sufficient to maintain the catalyst composition fluidized.

It may be necessary to put additional heat into the first reaction zone. This may be done in several ways. The liquid hydrocarbon may be preheated to temperatures of about 400°–950°F. before introduction into the first reaction zone. Small quantities of oxygen or oxygen-containing gas may be injected along with the fluidizing steam to produce the highly exothermic reaction

$$C + O_2 \rightleftarrows CO_2 + 169{,}200 \text{ Btu}$$

Another method would include preheating the steam. A still further method would include electrical heating of the catalyst composition bed or other indirect methods of heating the bed. Furthermore, any combination of each of these methods could also be employed.

Treatment of the liquid hydrocarbon containing feedstream, under the given operating conditions, in the presence of the particulate alkali metal catalyst composition produces a vaporous product and a solid hydrocarbon material which deposits on the particulate alkali metal composition. The vaporous product comprises CH_4 and other light hydrocarbons. These other light hydrocarbons may include C_2 to C_4 hydrocarbons and normally liquid hydrocarbon products including benzene and toluene depending on the initial feedstream employed. When steam is used as fluidizing gas, the vaporous product may also include small amounts of H_2, CO and CO_2 arising from some reaction of the fluidizing steam. The vaporous product is removed from the first reaction zone **102** by line **104.**

A portion of the particulate catalyst composition with the solid hydrocarbon material deposition is then passed via line **105** to a second reaction zone **106.** The second reaction zone is operated at a pressure above 200 psig, preferably between about 250 and 1,500 psig, more preferably between about 400–1,000 psig and at a temperature above 1,000°F., preferably between about 1,000°–1,600°F., more preferably between about

1,100° and 1,500°F., most preferably between about 1,200° and 1,450°F.

The temperature in the second reaction zone may be lower than in the first reaction zone. Thus, when the temperature in the first reaction zone is 1,300°–1,600°F., the temperature in the second reaction zone may be 1,100°–1,300°F.

Steam is introduced into the second reaction zone **106** via line **107.** An oxygen-containing gas such as air or oxygen may be introduced into the second reaction zone via line **108** to provide some of the heat or the heat may be provided by preheating the steam or by electrical heating or other indirect heating methods.

Suitable steam rates in the second reaction zone to obtain practical steam conversion, are steam-to-carbon in solid hydrocarbon material feed of the second reaction zone mole ratio between 1 to 10 and preferably between 1.5 to 5 and more preferably between 2 and 3.

When an oxygen-containing gas is introduced into the second reaction zone, the amount injected is that quantity required to maintain the desired temperature.

In the second reaction zone, at the start of the process, is maintained a bed of the same catalyst composition as that initially employed in the first reaction zone. When the process is in operation, there is interchange of portion of the catalyst composition between the first and the second reaction zones via line **105** and between second and first reaction zones via line **111.** The carbon content of the catalyst composition bed of the second reaction zone will therefore be lower than that of the first reaction zone when the process is in operation.

The second reaction zone may be fixed, moving or fluid bed, the latter two being preferred. The bed in the second reaction zone need not be in the same state as that of the first reaction zone, that is, if the first reaction zone has a fluidized bed, the second reaction zone need not have a fluidized bed.

At least a portion of solid hydrocarbon material deposition reacts with steam in the presence of the particulate catalyst composition under the above given conditions in the second reaction zone to produce a gaseous product comprising CO_2, CO, H_2 and CH_4. The gaseous product is removed from the second reaction zone via line **109** and combined with the vaporous product removed from the first reaction zone via line **104.** The combined product stream recovered via line **110** is rich in methane and comprises more than about 20 mole % methane based on the total product stream.

The combined product stream may be put through separating means (not shown) to separate the methane containing gases from the normally liquid product. If desired, the liquid product may be further fractionated to heavier and lighter fractions or aromatic hydrocarbons may be separated from the liquid products. Part or all of the liquid product may be recycled to the first reaction zone or to the second reaction zone.

In another embodiment, the gaseous product of the second reaction zone can be treated (e.g., by condensation) to remove unreacted steam and, if desired, further treated to remove CO_2 by conventional means prior to combining the remaining gaseous product with part or all of the vaporous product of the first reaction zone.

EXAMPLE

Thirteen and four-tenths pounds per hour of a petroleum vacuum residuum with a hydrogen to carbon mole ratio of 1.4/1 is introduced continuously into a first reaction zone of 0.6 cubic foot volume to contact a catalyst composition of potassium carbonate mixed with gamma alumina. At the start of the process, the potassium carbonate calculated as the carbonate is present as 33 wt. % of the composition, the balance being the alumina. The catalyst composition is maintained in fluidized state by the introduction of a sufficient amount of steam to keep the solids fluidized.

The first reaction zone is maintained at a temperature of 1,265°F. and a pressure of 600 psig.

Vaporous product in the amount of 113 standard cubic feet per hour is produced and 6.8 lb./hr. of solid hydrocarbon material is laid down on the particulate fluidized bed. The vaporous product of the first reaction zone has the following composition.

Component	Mole %
CH_4	66.2
C_2 to C_4 hydrocarbons	32.9
C_5+ normally liquid hydrocarbons	0.9

Of the 0.9 mole % of C_5^+ hydrocarbons, 0.8 mole % consists of aromatic hydrocarbons, predominantly benzene and toluene.

A portion of the particulate composition with the solid hydrocarbon material deposition is passed to a second reaction zone wherein is maintained a fluidized bed of the same catalyst composition as is present initially in the first reaction zone. Steam is introduced into the second reaction zone at a rate of 2.4 mole steam per mole carbon in solid hydrocarbon material introduced into the second reaction zone. Three hundred and thirty eight standard cubic feet per hour of gaseous product, exclusive of unconverted steam, are obtained from the second reaction zone.

Product Distribution of the Second Reaction Zone:

Component	Mole %
CH_4	15
CO	12
CO_2	37
H_2	36

The vaporous product of the first reaction zone and the gaseous product of the second reaction zone are combined into one stream for subsequent separation into the desired gases and liquid product. Methane content of the combined stream is 27 mole % of the total reaction product stream.

The amount of methane and high BTU content C_2 to C_4 hydrocarbons produced in the total gaseous stream by the two-stage process of the present invention is greater than that which could be produced from a single stage process. Furthermore, significant amount of valuable benzene and toluene are produced by the present process. The heating value of the combined stream is about 560 BTU per cubic foot after condensation of the C_5^+ material.

I claim:

1. A process for producing a methane-rich stream by treating a hydrocarbon feedstream containing a liquid hydrocarbon, which comprises:

a. treating said feedstream in a first reaction zone maintained at a pressure between about 250 and 1,500 psig, and at a temperature between about 1,200° and 1,450°F in the presence of particulate catalyst composition comprising an alkali metal compound and a solid particulate material to produce a vaporous product comprising CH_4 and other light hydrocarbon products, and a solid hydrocarbon material which deposits on said particulate composition;

b. removing said vaporous product from said first reaction zone;

c. passing at least a portion of said particulate catalyst composition with the solid hydrocarbon material deposition to a second reaction zone maintained at a pressure between about 250 and 1,500 psig and at a temperature between about 1,000°F and 1,600°F to contact steam introduced into said second reaction zone at a steam-to-carbon in solid hydrocarbon material of the second reaction zone mole ratio between 1 and 10, whereby at least a portion of the solid hydrocarbon material deposition is converted into a gaseous product comprising CH_4, H_2, CO and CO_2; and

d. removing said gaseous product from said second reaction zone.

2. The process of claim **1**, wherein an oxygen-containing gas is introduced into said second reaction zone.

3. The process of claim **1**, wherein steam is introduced into said first reaction zone.

4. The process of claim **1**, wherein said catalyst composition comprises K_2CO_3 or Cs_2CO_3 deposited on said solid particulate material.

5. The process of claim **1**, wherein said catalyst composition comprises K_2CO_3 or Cs_2CO_3 mixed with said solid particulate material.

6. The process of claim **1**, wherein said solid particulate material is selected from the group consisting of alumina, silica-alumina, crude or partially purified bauxite or mixtures thereof.

7. The process of claim **1**, wherein carbon is deposited on said solid particulate material.

8. The process of claim **1**, wherein said solid particulate material is activated carbon and said alkali metal compound is mixed therewith.

9. The process of claim **1**, wherein said feedstream contains at least 10 weight percent liquid hydrocarbons having a boiling point above about 900°F at atmospheric pressure.

10. The process of claim **1**, wherein said alkali metal (calculated as the metal) comprises between 0.5 and 35 weight percent of the solids in said first reaction zone.

11. The process of claim **1**, wherein said feedstream comprises a petroleum residuum.

12. The process of claim **1**, wherein said first and second reaction zones are maintained at pressures between about 400 and 1,000 psig.

13. The process of claim **1**, wherein said second reaction zone is maintained at a temperature between about 1,100° and 1,500°F.

14. The process of claim **1**, wherein said second reaction zone is maintained at a temperature between about 1,200° and 1,450°F.

15. A process for producing a methane-rich stream by treating a hydrocarbon feedstream containing a liquid hydrocarbon, which comprises:

a. treating said feedstream in a first reaction zone maintained at a pressure between about 250 and 1500 psig and at a temperature between about 1,000°F and 1,600°F in the presence of a particulate catalyst composition comprising an alkali metal compound and a solid particulate material to produce a vaporous product comprising CH_4 and other light hydrocarbon products, and a solid hydrocarbon material which deposits on said particulate catalyst composition;

b. removing said vaporous product from said first reaction zone;

c. passing at least a portion of said particulate catalyst composition with the solid hydrocarbon material deposition to a second reaction zone maintained at a pressure between about 250 and 1,500 psig and at a temperature between about 1,000° and 1,600°F to contact steam introduced into said second reaction zone at a steam-to-carbon in solid hydrocarbon material of the second reaction zone mole ratio between 1 and 10, whereby at least a portion of the solid hydrocarbon material deposition is converted into a gaseous product comprising CH_4, H_2, CO and CO_2;

d. removing said gaseous product from the second reaction zone;

e. combining the gaseous product of step (d) with the vaporous product of step (b) to produce a combined stream rich in methane content;

f. treating the methane-rich stream of step (e) to separate normally gaseous products from normally liquid products; and

g. recycling at least a portion of the normally liquid products to said second reaction zone.

16. A process for producing a methane-rich stream by treating a hydrocarbon feedstream containing a liquid hydrocarbon, which comprises:

a. treating said feedstream in a first reaction zone maintained at a pressure between about 250 and 1,500 psig, and at a temperature between about 1,000° and 1,600°F in the presence of a particulate catalyst composition comprising an alkali metal compound and a solid particulate material to produce a vaporous product comprising CH_4 and other light hydrocarbon products, and a solid hydrocarbon material which deposits on such particulate catalyst composition;

b. removing said vaporous product from said first reaction zone;

c. passing at a portion of said particulate catalyst composition with the solid hydrocarbon material deposition to a second reaction zone maintained at a pressure between about 250 and 1,500 psig and at a temperature between about 1,000°F and 1,600°F to contact steam introduced into said second reaction zone at a steam-to-carbon in solid hydrocarbon material of the second reaction zone mole ratio between 1 and 10, whereby at least a portion of the solid hydrocarbon material deposition is converted into a gaseous product comprising CH_4, H_2, CO and CO_2;

d. removing said gaseous product from said second reaction zone;

e. treating said vaporous product of step (b) to separate the normally liquid hydrocarbons from the normally gaseous product; and

f. recycling at least a portion of said normally liquid hydrocarbons to the second reaction zone.

17. A process for producing a methane-rich stream by treating a hydrocarbon feedstream containing a liquid hydrocarbon, which comprises:

a. treating such feedstream with an oxygen-containing gas in a first reaction zone maintained at a pressure between about 250 and 1,500 psig, and at a temperature between about 1,000°F and 1,600°F in the presence of a particulate catalyst composition comprising an alkali metal compound and a solid particulate material to produce a vaporous product comprising CH_4 and other light hydrocarbon products, and a solid hydrocarbon material which deposits on said particulate catalyst composition;

b. removing said vaporous product from said first reaction zone;

c. passing at least a portion of said particulate catalyst composition with the solid hydrocarbon material deposition to a second reaction zone maintained at a pressure between about 250 and 1,500 psig and at a temperature between about 1,000°F and 1,600°F to contact steam introduced into said second reaction zone at a steam-to-carbon in solid hydrocarbon material of the second reaction zone mole ratio between 1 and 10, whereby at least a portion of the solid hydrocarbon material deposition is converted into a gaseous product comprising CH_4, H_2, CO and CO_2; and

d. removing said gaseous product from said second reaction zone.

18. A process for producing a methane-rich stream by treating the hydrocarbon feedstream containing a liquid hydrocarbon, which comprises:

a. treating said feedstream in a first reaction zone maintained at a pressure between about 250 and 1,500 psig, and at a temperature between about 1,000°F and 1,600°F in the presence of a particulate catalyst composition comprising an alkali metal compound and a solid particulate material to produce a vaporous product comprising CH_4 and other light hydrocarbon products, and a solid hydrocarbon material which deposits on said particulate catalyst composition;

b. removing said vaporous product from said first reaction zone;

c. passing at least a portion of said particulate catalyst composition with the solid hydrocarbon material deposition to a second reaction zone maintained at a pressure between about 250 and 1,500 psig and at a temperature between 1,000°F and 1,600°F, said first reaction zone being maintained at a higher temperature than said second reaction zone, to contact steam introduced into said second reaction zone at a steam-to-carbon in solid hydrocarbon material of the second reaction zone mole ratio between 1 and 10, whereby at least a portion of the solid hydrocarbon material deposition is converted into a gaseous product comprising CH_4, H_2, CO and CH_2; and

d. removing said gaseous product from said second reaction zone.

19. A process for producing a methane-rich stream by treating a hydrocarbon feedstream containing a liquid hydrocarbon, which comprises:

a. treating such feedstream in a first reaction zone maintained at a pressure between about 250 and 1,500 psig, and at a temperature between 1,300° and 1,600°F in the presence of a particulate catalyst composition comprising an alkali metal compound and a solid particulate material to produce a vaporous product comprising CH_4 and other light hydrocarbon products, and a solid hydrocarbon material which deposits on said particulate catalyst composition;

b. removing said vaporous product from said first reaction zone;

c. passing at least a portion of said particulate catalyst composition with the solid hydrocarbon deposition to a second reaction zone maintained at a temperature between 1,100° and 1,300°F to contact steam introduced into said second reaction zone at a steam-to-carbon in solid hydrocarbon material of the second reaction zone mole ratio between **1** and **10,** whereby at least a portion of the solid hydrocarbon material deposition is converted into a gaseous product comprising CH_4, H_2, CO, and CO_2; and

d. removing said gaseous product from said second reaction zone.

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