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54 Process for producing synthesis gas by partial combustion of hydrocarbons.

57 Process for the production of synthesis gas and higher hydrocarbons in which a saturated hydrocarbon and an oxygen containing gas having a ratio of hydrocarbon to oxygen of greater than the stoichiometric ratio for complete combustion are introduced into a bed of an inert particulate material. The upward flow rate of the hydrocarbon/oxygen containing gas stream is sufficient to fluidise or to produce a spouting action of the bed material, whereby the particulate material is thrown up above the bed surface and subsequently falls back into the bed. The hydrocarbon and oxygen containing gas are ignited and reacted together, and the products of the reaction withdrawn.

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TITLE MODIFIED  
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CONVERSION PROCESS

The present invention relates to a process for the production of a mixture of gases comprising carbon monoxide and hydrogen (hereinafter referred to as synthesis gas) and higher hydrocarbons in a particulate bed reactor.

5 The use of fluidised beds for various applications is well known. The fluidisation process involves flowing gas through a bed of particulate material at a rate at which the bed becomes highly turbulent and rapid mixing of the particles occurs. Materials may be introduced to and be reacted in the bed.

10 Spouted bed technology comprises passing a high velocity stream of gas vertically upwards through a mass of solid particles. The high velocity gas stream causes the particles to ascend rapidly in a hollowed central spout within the bed. In addition to particle motion within the spout there is some particle back mixing in the area surrounding the spout giving a particle circulation pattern  
15 outside the spout. The feed gas may have sufficient upward flow to create a fountain of particles above the bed or in a deeper bed may give a very high circulation rate of solid particles within the bed. In each case a cycle of solid particle movement is  
20 established. A review of developments in spouted bed technology appears in the Canadian Journal of Chemical Engineering, Volume 52, page 129, 1974.

25 It has now been found that fuel rich flames can be stabilised in a particulate bed reactor and that the exit gas stream contains useful products.

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Thus according to the present invention there is provided a process for the production of synthesis gas and higher hydrocarbons in which (a) a saturated hydrocarbon and an oxygen containing gas having a ratio of hydrocarbon to oxygen of greater than the  
5 stoichiometric ratio for complete combustion are introduced into a bed of an inert particulate material, (b) the upward flow rate of the hydrocarbon/oxygen containing gas stream being sufficiently large to fluidise or to produce a spouting action of the bed material, whereby at least a part of the particulate material is  
10 thrown up above the bed surface and subsequently falls back into the bed, (c) the hydrocarbon and oxygen containing gas being ignited and reacted together and (d) the products of the reaction being withdrawn.

The invention includes a process having a bed in which the  
15 upward flow rate of the hydrocarbon/oxygen containing gas stream causes surface bubbling of the bed sufficient to throw particulate material up into the freeboard.

The invention also includes a process in which the upward flow rate of the hydrocarbon/oxygen containing gas stream forms a  
20 fountain of particles above the bed surface, the particles falling back into the bed.

The hydrocarbon and oxygen containing gas may be pre-mixed before being introduced into the bed through a nozzle. Alternatively the reactant gases may be allowed to mix at the point  
25 of injection to the bed.

The saturated hydrocarbon is preferably a gaseous paraffinic hydrocarbon such as substantially pure methane or ethane or mixtures of hydrocarbons comprising substantial proportions of methane and/or ethane, for example those obtained from natural hydrocarbon gas  
30 reservoirs which may also contain significant quantities of carbon dioxide. The oxygen containing gas may be for example air or an air/oxygen mixture. Also the oxygen containing gas may be pure oxygen.

The hydrocarbon and/or the oxygen containing gas may be pre-  
35 heated, if required prior to introduction to the bed.

The reactor may also be equipped with ancillary heating means, for example, heating coils in the bed or by direct fired heating of the reactor walls.

5 The preferred composition of the saturated hydrocarbon/oxygen containing gas mixture is pressure dependent. At atmospheric pressure the preferred composition is 1.1 to 5 times the stoichiometric ratio of hydrocarbon/oxygen for complete combustion but these limits are extendible if operation at system pressures of greater than atmospheric are envisaged. Commercial reactor systems  
10 would probably be operated at pressures above atmospheric and up to 50 bar or even higher.

The particulate bed material may be an inert temperature resistant refractory material which may include firebrick, quartz, carborundum, zirconia, silicon carbide, ceramics and certain forms  
15 of carbon e.g. high density coke may be used.

The shape of the particulate bed material may be, for example, spherical, cylindrical, or amorphous. The particle size may vary from 0.01 to 10 mm in diameter dependent upon the particle density, the diameter of the reactor and feed inlet, and the feed gas flow  
20 rate. The particle size distribution is preferably as uniform as possible.

The materials of construction of the reactor vessel may be for example steel, quartz, carbon fibre or refractory material dependent upon material availability and location and size of the reactor.  
25 The reactor may be insulated to reduce heat loss.

The reaction may be initiated in a number of ways. For example, the particulate bed material may be pre-heated by igniting and burning a near stoichiometric mixture in the bed until the bed temperature is great enough to sustain the combustion of the excess  
30 stoichiometric hydrocarbon/oxygen mixtures. A typical steady state bed temperature is of the order 500-1500°C.

The products of the reaction are preferably withdrawn from above the bed. The preferred products include acetylene, ethylene and synthesis gas (carbon monoxide and hydrogen) and quantities of  
35 aromatic products e.g. benzene.

The reactor vessel containing the bed of particulate material may be shaped so as to encourage recirculation of bed particles in a vertical direction. For a single inlet feed nozzle, the preferred shape of the base portion is conical. The cone angle measured from the vertical is preferably from 10° to 40°.

In order to reduce the amount of carbon (soot) formation in the final product, steam or water may be injected into the bed together with the reactant gases and/or injected into the product gases as a quench. This is particularly desirable when operating at pressures greater than one bar. It is believed that the injection of steam or water (quenching) reduces the temperature of the product gases and stops or reduces further reaction to less useful products and/or soot. An alternative mode of quench is envisaged if it is required to increase the amount of unsaturated hydrocarbons in the product gases. This mode comprises the injection of, for example, a liquid saturated hydrocarbon e.g. propane, butane or gasoline, into the hot product gases and to thereby increase the content of light unsaturated hydrocarbons e.g. ethylene, acetylene in the product gases.

It is also envisaged that for the conversion of large quantities of hydrocarbon and oxygen containing gas, an array of reactors could be used. Also a single bed containing one or more adjacent inlet nozzles may be used.

It is also possible if desired to introduce further gaseous hydrocarbon to the bed through a further nozzle or nozzles. This further hydrocarbon feed may have the same composition as the saturated hydrocarbon feed or may be different. The further nozzle or nozzles may direct the further hydrocarbon feed in a counter current, parallel, perpendicular or other direction relative to the spouting hydrocarbon gas feed direction.

The invention will now be described by way of example only and with reference to the accompanying drawing.

The drawing shows a schematic layout of a reactor and ancillary equipment.

The reactor 1 takes the form of a lagged elongate quartz column

2 having a conical base portion 3, the angle of the cone from the vertical being 20°. The base portion of the reactor contains a slumped bed 4 of particulate material having a particle size of the order 1-1.5 mm diameter. The particulate materials were crushed  
5 firebrick, silicon carbide, quartz and zirconia. The base of the column is adapted to receive a nozzle 5 for the introduction of reactants. The nozzle outlet may be adjusted vertically within the bed of particulate material. The upper portion 6 of the reactor is open to form an outlet for withdrawal of the product gases. A line  
10 10 enables samples of the products to be withdrawn from the product gas stream.

The nozzle 5 is connectable to a supply of air 7 or other oxygen containing gas under appropriate pressure and to a supply of methane 8. A suitable supply may comprise cylinders of hydrocarbon  
15 e.g. methane, and air or oxygen linked to the nozzle through a mixer and gas pressure and flow rate measuring devices such as manometers and rotameters (not shown).

The reactor may also have an additional nozzle or nozzles for supplying further methane or other hydrocarbon to the bed (not shown  
20 in the drawing). The reactor 1 is lagged with a suitable insulating material 9.

A number of techniques may be used for start up of the reactor. In the present example, the ignition source was a gas burner (not shown) located at the outlet portion 6 of the column.

25 During start up of the reactor, a pre-mixed gas stream of hydrocarbon and air was passed under pressure to the nozzle 5 in the base portion 3 of the column. The velocity of the gas stream was sufficient to cause a fountain 11 of bed particles in the freeboard above the bed.

30 The gas stream used was very fuel rich and consequently the gas mixture was ignited by the gas burner and a flame stabilised at the exit of the reactor. The air flowrate was increased, bringing the mixture closer to stoichiometric, until the flame began to move slowly back down the reactor. A flame was stabilised at the surface  
35 of the slumped bed and the fuel flowrate reduced slightly to obtain

a near stoichiometric mixture. When the bed temperatures had equilibrated, the fuel flowrate was increased and a low flowrate of oxygen was added to the bed. The air flowrate was then reduced and both the fuel and the oxygen increased to maintain the stable flame and the spouting action of the bed. This procedure was repeated until the feed composition was entirely fuel and oxygen. The total feed mixture was always maintained on the rich side of stoichiometric close to or beyond the rich limit of flammability. At atmospheric pressure, the rich limit of flammability corresponds to a methane/oxygen mole ratio of 1.5.

The constituents and composition of the reactant gases were ascertained by means of conventional techniques. This procedure was repeated for a number of fuel rich hydrocarbon/oxygen reactant compositions and different particulate bed materials. The products obtained from the reaction may include carbon monoxide and hydrogen (synthesis gas), acetylene, and ethylene.

Table 1 shows results for the reaction of methane and oxygen in a reactor using various bed materials. The bed materials generally had particle size of 1 to 1.5 mm diameter and were crushed firebrick, quartz and silicon carbide. The increased carbon molar selectivities to  $C_2$  and higher hydrocarbons is shown for all the bed materials for fuel rich conditions as the feed composition is made increasingly fuel rich up to and beyond the rich limit of flammability.

Table 2 shows results for the reaction of methane and air in a reactor. The bed material used was zirconia spheres of the order 1-1.2 mms diameter. The carbon molar selectivities and feed conversions achieved are similar to those obtained with oxygen.

Calculations have shown that the residence time of the reactant gases in the hot zone is desirably less than 1 millisecond in order to avoid an undesirably high degree of cracking of the products to soot or other compounds. It may be possible to use longer residence times at low or atmospheric pressures.

The following experiments relate to an alternative process mode in which a lower velocity gas stream was used so as to cause

fluidisation of the bed material and/or surface bubbling of the bed material. The fluidisation and/or bubbling was sufficient to cause the particulate material to be thrown up into the freeboard, the material returning to the bed.

5 Table 3 shows results obtained in a fluidised bed reactor with a methane/oxygen feed. The bed comprised 0.25-0.85 mm particles of zirconia. The reactant gases were fed to the reactor through a distributor plate at a sufficient velocity to attain turbulent fluidisation with bed material thrown randomly into the gas phase or  
10 freeboard above the bed.

Experiments with fuel rich mixtures close to or beyond the limit of flammability using conventional fluidised bed operation at one bar pressure and with an inert bed material generally resulted in flame lift off or instability. At the onset of surface bubbling  
15 (or localised spouting) a more stable combustion regime ensued and partial oxidation with production of CO/H<sub>2</sub> and C<sub>2</sub>'s resulted. This effect persisted into the complete spouting regime. It is believed that the stable combustion of mixtures close to or beyond the limit of flammability results from the countercurrent heat transfer  
20 between the descending hot particulate material and the ascending gases thereby enabling pre-heat of incoming feed gases.

As the pressure of operation is increased the upper flammability is extended to richer mixtures. Thus, the need for particulate heat recirculation for stable combustion is greater at  
25 lower operating pressures than at higher operating pressures. However, by application of the present invention, the limit of flammability can be further extended at increased pressures by particulate heat recirculation in a similar way as at atmospheric  
30 pressure.

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Table 1

Conversion of methane and oxygen using various bed materials

Run No.	Feed inlet gas composition (% mole)		Total Flowrate (l/min)	Feed (CH <sub>4</sub> /O <sub>2</sub> ) (Mole ratio)	% Conversion of CH <sub>4</sub> feed	Exit dry gas composition (% mole)						Carbon Molar Selectivity to C <sub>2</sub> and higher hydrocarbons (%)	Bed Material			
	O <sub>2</sub>	CH <sub>4</sub>				N <sub>2</sub>	N <sub>2</sub>	H <sub>2</sub>	CO	CO <sub>2</sub>	CH <sub>4</sub>			C <sub>2</sub> 's	C <sub>3</sub> -C <sub>6</sub> aromatic	
1	32.9	63.7	3.4	10.7	1.93	70.9	3.6	42.0	23.3	3.3	18.7	8.7	0.2	0.1	36.2	Firebrick
2	43.8	53.4	2.8	11.0	1.22	90.3	2.9	48.6	35.1	5.0	5.1	3.2	0.01	0.04	13.2	"
3	51.3	46.2	2.5	11.3	0.90	99.4	3.2	47.0	37.2	12.2	0.3	0.1	0	0.01	0.3	"
4	38.2	58.9	2.9	16.0	1.54	87.1	2.8	51.9	26.7	2.5	7.2	7.6	0.2	0.13	38.3	"
5	36.2	59.2	4.6	23.1	1.64	82.3	4.6	49.9	23.3	3.1	10.6	8.1	0.1	0.23	36.8	"
6	36.6	59.4	4.0	23.1	1.62	91.8	3.4	55.4	26.4	3.4	4.1	7.1	0	0.16	33.6	Quartz
7	36.5	59.2	4.4	23.5	1.62	90.6	4.0	52.7	26.4	3.3	5.1	8.1	0.1	0.18	36.2	Silicon carbide

Table 2  
Conversion of methane and air using zirconia bed material

Total Flow Rate (litres/min)	Feed Ratio (CH <sub>4</sub> /O <sub>2</sub> )	% Conversion of CH <sub>4</sub> feed	% Carbon Molar Selectivity C <sub>2</sub> + CO CO <sub>2</sub> soot	Bed Temperature (°C)	Product Gas H <sub>2</sub> /CO (Mole Ratio)
45	1.18	92	27 63 10 0	1040	1.6
33	1.23	89	27 61 11 1	1065	1.6

Table 3  
Conversion of methane and oxygen in a fluidised bed reactor using zirconia bed material

Gas Hourly Space Velocity (hour <sup>-1</sup> )	Feed Ratio (CH <sub>4</sub> /O <sub>2</sub> )	% Conversion of CH <sub>4</sub> feed	% Carbon Molar Selectivity C <sub>2</sub> + CO CO <sub>2</sub>	Bed Temperature (°C)	Product Gas H <sub>2</sub> /CO (Mole Ratio)
25300	1.54	67	33 58 8	1050	1.1
19000	1.70	85	40 46 10	1000	2.1

Claims:

1. A process for the production of synthesis gas and higher hydrocarbons in which (a) a saturated hydrocarbon and an oxygen containing gas having a ratio of hydrocarbon to oxygen of greater than the stoichiometric ratio for complete combustion are introduced  
5 into a bed of an inert particulate material, (b) the upward flow rate of the hydrocarbon/oxygen containing gas stream being sufficient to fluidise or to produce a spouting action of the bed material, whereby at least a part of the particulate material is thrown up above the bed surface and subsequently falls back into the  
10 bed, (c) the hydrocarbon and oxygen containing gas being ignited and reacted together, and (d) the products of the reaction being withdrawn.
2. A process according to claim 1 in which the upward flow rate of the hydrocarbon/oxygen containing gas stream causes surface bubbling  
15 of the bed.
3. A process according to claim 1 in which the upward flow rate of the hydrocarbon/oxygen containing gas stream forms a fountain of particles above the bed surface, the particles falling back into the bed.
- 20 4. A process according to any of claims 1 to 3 in which the hydrocarbon and oxygen containing gas are pre-mixed prior to introduction to the bed.
5. A process according to any of claims 1 to 4 in which the hydrocarbon gas comprises methane, ethane or natural gas.
- 25 6. A process according to any of the preceding claims in which the oxygen containing gas is oxygen or air.

7. A process according to any of the preceding claims in which the hydrocarbon and/or the oxygen containing gas are pre-heated prior to introduction to the bed.

5 8. A process according to any of the preceding claims in which the composition of hydrocarbon gas and oxygen containing gas is 1.1 to 5 times the stoichiometric ratio of hydrocarbon/oxygen for complete combustion.

9. A process according to any of the preceding claims operated at a pressure of greater than atmospheric pressure.

10 10. A process according to any of the preceding claims in which the bed of particulate material comprises firebrick, quartz, carborundum, zirconia, silicon carbide, ceramic or forms of carbon.

11. A process according to claim 10 in which the particulate size diameter is 0.01-10 mm.

15 12. A process according to any of the preceding claims in which the bed has ancillary heating means.

13. A process according to any of the preceding claims in which the reaction is initiated by preheating the bed material by igniting and burning a near stoichiometric hydrocarbon/oxygen containing gas mixture in the bed until the bed temperature is sufficient to  
20 sustain combustion of an hydrocarbon/oxygen containing gas mixture having a ratio of hydrocarbon to oxygen of greater than the stoichiometric ratio for complete combustion.

14. A process according to any of the preceding claims in which  
25 the reaction is quenched.

15. A process according to claim 14 in which the reaction is quenched by the introduction of steam or water.

16. A process according to claim 14 in which the reaction is quenched by the introduction of a liquid saturated hydrocarbon into  
30 the hot product gas.

17. A process according to any of the preceding claims in which further hydrocarbon gas is introduced to the bed.

18. A process according to claim 17 in which the further hydrocarbon gas is different in composition or constitution from the  
35 hydrocarbon gas.

19. A process according to claim 17 or claim 18 in which the further hydrocarbon gas is introduced parallel, perpendicular, or countercurrent to the hydrocarbon/oxygen containing gas mixture.

20. A process according to any of the preceding claims which is  
5 carried out in one or more particulate beds.

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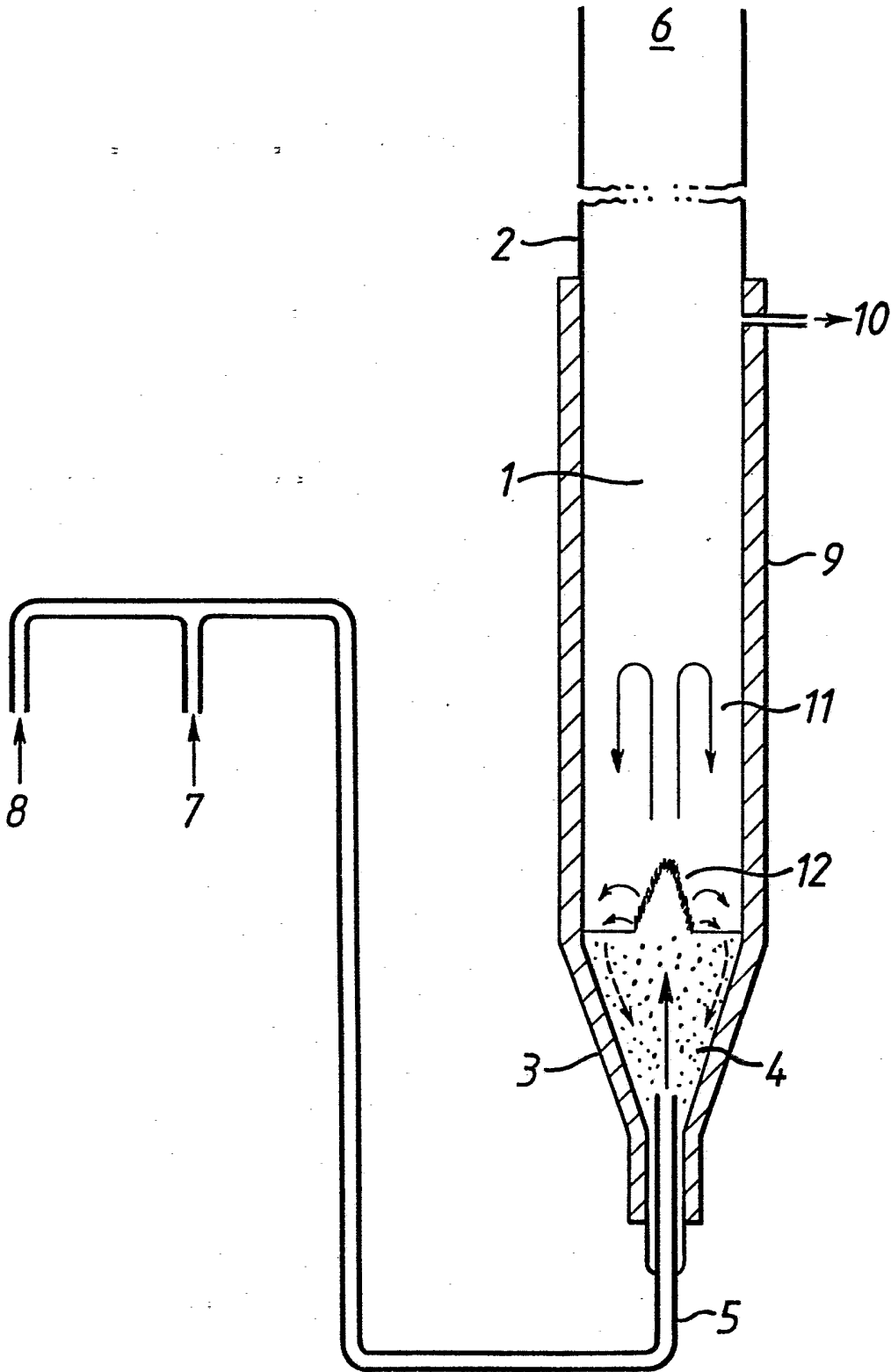
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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	GB-A- 568 913 (STANDARD OIL DEVELOPMENT)		C 01 B 3/44
X	FR-A-1 182 135 (BASF) * Page 1, left-hand column, paragraph 2; page 2, right-hand column, paragraphs 3,4 *	1,4,7	
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			C 01 B
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 08-08-1985	Examiner VAN BELLINGEN I.
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