

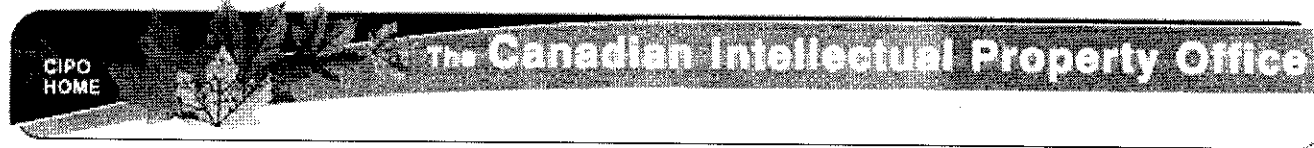


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(54) PRODUCTION OF HYDROGEN AND CARBON MONOXIDE

(54)

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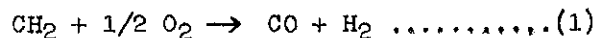
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- Claims Image
- Disclosures Image
- Drawings Image

The present invention relates to a process for the production of hydrogen and carbon monoxide from hydrocarbons. More particularly, the invention relates to controlled partial combustion of hydrocarbons in the production of hydrogen and carbon monoxide.

The importance of hydrocarbon conversion processes in which hydrogen and carbon monoxide are produced has grown rapidly in recent years because of the growing requirements for such product gases in a number of other processes including, for example, the direct reduction of iron ore and the synthesis of methanol, hydrocarbons by Fischer-Tropsch, ammonia, urea and the like.

One of the principal conversion processes used in the production of hydrogen and carbon monoxide is non-catalytic partial combustion or oxidation of the hydrocarbon feedstock. Equation (1) illustrates the reaction which is sought in all such partial combustion processes:



CH₂ is indicated as the hydrocarbon reactant merely for purposes of illustrating the general character of reactants and products.

The temperature at which the reaction of equation (1) is conducted is of substantial importance because temperature strongly influences the extent of completing undesirable reactions whereby hydrocarbons decompose



forming carbon or soot and hydrogen. The presence of soot in the products of partial combustion is undesirable irrespective of the subsequent use of the product gas. Extensive and expensive provisions are frequently necessary to remove
5 the soot from the products to prevent its accumulation in equipment forcing periodic interruption of the process for cleaning.

Generally, as the temperature at which partial combustion is conducted is increased, the amount of soot
10 formed is decreased. As the proportion of oxygen to hydrocarbon in the feed to the partial combustion zone is increased from values corresponding to stoichiometric partial combustion to values corresponding to stoichiometric complete combustion, the temperature at which the combustion
15 reaction proceeds rises because complete combustion is a much more highly exothermic reaction than partial combustion. In commercial partial combustion processes, the elevated temperatures required to lessen soot formation attending the reaction to hydrogen and carbon monoxide are
20 generally obtained by supplying oxygen in substantial excess of stoichiometric partial combustion requirements, thereby increasing the exothermicity of the partial combustion reaction. Such an increase in the oxygen to hydrocarbon ratio affords at best only a partial solution to the
25 soot problem while it has the unfortunate consequences of increasing the oxygen requirement for a given volume of product gas and of tending to increase the amounts of carbon dioxide and water appearing in the product gas. Increased oxygen consumption requires a much larger and more
30 costly air-separation plant than is otherwise necessary to

provide the process oxygen requirement. For many subsequent uses of partial combustion products, such as the direct reduction of iron ore and the synthesis of methanol, oxidizing constituents such as water and carbon dioxide
5 must be substantially absent.

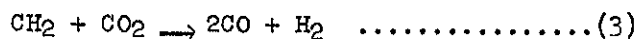
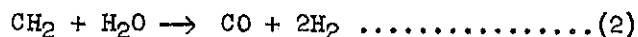
In accordance with the present invention there is provided a process which comprises introducing a hydrocarbon feed and a combustion-supporting gas containing sufficient total oxygen to satisfy the stoichiometric
10 total oxygen requirement for conversion of the hydrocarbon feed to hydrogen and carbon monoxide into an externally heated partial combustion zone maintained at a temperature above about 2500°F, by burning an auxiliary fuel at a higher temperature in a burning zone maintained in indirect
15 heat exchanging relationship with the partial combustion zone, thereby externally heating the partial combustion zone. Hydrogen and carbon monoxide are recovered from the externally heated partial combustion zone substantially free of soot.

20 Hydrocarbons which can be processed in accordance with the invention include those from natural gas to the heaviest oils. The gasification of normally liquid hydrocarbons has been a particularly troublesome process to conduct by conventional techniques because of the low re-
25 fractoriness of such feeds and consequent soot formation, but the present invention also provides a process by which such hydrocarbons are efficiently gasified without substantial soot formation.

30 Partial combustion of the hydrocarbon feed is preferably conducted at the lowest possible temperature in

view of accordingly reduced requirements for materials of construction and for providing heat to the reactants. At temperatures below about 2500°F., however, substantial soot formation occurs in connection with partial combustion, even when otherwise operating in accordance with the invention, so such temperatures are to be avoided. The reaction in the partial combustion zone is substantially soot-free where any temperature above about 2500°F. is maintained but there is no additional advantage gained by maintaining the partial combustion zone at very great elevated temperatures, i.e., above about 3000°F., while, as indicated, such very great elevated temperatures are somewhat disadvantageous in increasing requirements for materials of construction and for external heating of the partial combustion zone. For these reasons, it is preferred to maintain the partial combustion zone at a temperature from about 2500°F. to about 3000°F., and more preferably at about 2600°F.

Conversion of the hydrocarbons in the partial combustion zone is obtained by reaction with a combustion-supporting gas under controlled conditions. As used herein, a combustion-supporting gas includes molecular oxygen, carbon dioxide, steam or admixtures thereof. The combustion-supporting gas provides the total oxygen requirements of the partial combustion process. When steam and/or carbon dioxide is used, the desired partial combustion reactions are illustrated by equations (2) and (3) each of which is highly endothermic.



The combustion-supporting gas preferably used is molecular

oxygen because its reaction with hydrocarbons is exothermic, thereby providing a portion of the heat required to heat the reactants to the elevated temperature at which the reaction is desirably maintained. Molecular oxygen can
5 be introduced as the pure component, as oxygen-enriched air, or as air. For many subsequent uses of the product hydrogen and carbon monoxide, nitrogen is an undesirable diluent which when present must be removed, so the partial
10 combustion is preferably carried out with relatively pure oxygen in these instances and substantially no diluent is introduced.

As is seen from equations (2) and (3), the use of steam tends to favor higher proportions of hydrogen in the product gas while the use of carbon dioxide tends to
15 favor higher proportions of carbon monoxide in the product gas. Thus, relatively wide variation in the ratio of hydrogen to carbon monoxide in the product gas is attainable by appropriate variation in the composition of the combustion-supporting gas.

20 The total oxygen supplied in the combustion-supporting gas to the partial combustion zone must be carefully controlled to obtain soot-free operation. At least enough total oxygen as molecular oxygen, steam, and/or carbon dioxide must be supplied in all cases to satisfy
25 the stoichiometry of partial combustion of the hydrocarbon feed to hydrogen and carbon monoxide. For complete hydrocarbon conversion, a slight excess in total oxygen over this stoichiometric minimum is supplied, not more than about 10 percent and preferably between about 2 and
30 about 5 percent. Soot-free operation in the externally

heated partial combustion zone can also be obtained where the total oxygen provided is in substantial excess of the stoichiometric minimum provided that the above mentioned temperatures are maintained in the partial combustion zone

5 by external heating. Of course, where the subsequent use of the product gas is such that the concentration of carbon dioxide and steam in the product gas be held to a minimum as in the case where the product gas provides reducing gas for the direct reduction of iron ore, only the

10 above preferred slight excess of total oxygen should be used. Where steam and/or carbon dioxide are used to supply an appreciable part of the total oxygen requirement, the partial combustion reaction is much more endothermic than where the combustion-supporting gas is principally

15 molecular oxygen, so that it is necessary to burn substantially greater amounts of auxiliary fuel in the burning zone in order to maintain proper temperatures in the partial combustion zone. While there is no actual limit to the amount of auxiliary fuel which can be burned in the

20 burning zone to supply heat to the partial combustion zone, for reasons of economics it is preferred to limit to some extent the requirements for auxiliary fuel and for external heating by providing at least sufficient molecular oxygen in the combustion-supporting gas to the partial combustion zone to keep the partial combustion reaction from

25 being highly endothermic as would be the case if steam and/or carbon dioxide alone constituted the combustion-supporting gas. Thus, irrespective of the steam and/or carbon dioxide content of the combustion-supporting gas,

30 it is preferred to include therein sufficient molecular

oxygen to give a weight ratio of molecular oxygen to hydrocarbon feed introduced to the partial combustion zone of about 0.35 to about 1.30, the precise value within this range being influenced by the character of the hydrocarbon feed, in particular the ratio of hydrogen to carbon in the hydrocarbon feed. Normally gaseous hydrocarbons have a relatively high ratio of hydrogen to carbon, so that when converting these hydrocarbons to hydrogen and carbon monoxide, it is preferred to provide a weight ratio of molecular oxygen to hydrocarbon feed introduced to the partial combustion zone of about 0.90 to about 1.30. In the case of normally liquid hydrocarbons, the weight ratio of molecular oxygen to hydrocarbon feed introduced to the partial combustion zone is preferably about 0.35 to about 0.90.

Under the conditions of total oxygen introduction described above, the reaction in the partial combustion zone is only slightly exothermic, isenthalpic, or somewhat endothermic. The heat required to maintain the partial combustion zone at suitably elevated temperatures is not solely obtained as in previous processes by providing substantially increased amounts of pure oxygen to the partial combustion zone to raise the exothermicity of the partial combustion reaction but is obtained in part in the present process by burning an auxiliary fuel, which can always be done with air, in the burning zone and thus externally heating the partial combustion zone. The advantages of this mode of operation even apart from the aspect of substantially soot-free conversion are manifold. For example, in a partial combustion process where the subsequent use of the product gas requires pure oxygen to be used exclusively

rather than air as the combustion-supporting gas, a substantial proportion of the heat requirement of the process is obtained by burning an auxiliary fuel in the burning zone with air, rather than pure oxygen, so that the consumption of oxygen as pure oxygen is at a near minimum and significantly lower than in prior partial combustion processes. Also as a result of limiting the pure oxygen supply to the partial combustion zone to a near minimum, as little as about one mol percent each of carbon dioxide and steam in the product gases can be obtained.

As indicated, the heat deficiency of the partial combustion zone with respect to the maintenance of suitably elevated temperatures therein is overcome by firing an auxiliary fuel, preferably with air, in the burning zone maintained in indirect heat exchanging relationship with the partial combustion zone. Since the temperature in the partial combustion zone is maintained at about 2600°F., firing of the auxiliary fuel in the burning zone must provide temperatures in excess of about 2800°F. therein in order to effect efficient heat transfer to the partial combustion zone. Generally, it is preferred to maintain a temperature difference between the two zones of about 200 to 500°F. The auxiliary fuel fired in the burning zone can be any suitable fuel, including, for example, the same hydrocarbon or mixture of hydrocarbons as is charged to the partial combustion zone for conversion to hydrogen and carbon monoxide. Where the products of the partial combustion zone are used in the direct reduction of iron ore, the tail gas from the iron ore converters can also be used as auxiliary fuel in the burning zone. Combustion in the

burning zone is conducted with sufficient air to obtain substantially complete and efficient combustion of the auxiliary fuel. The supply of auxiliary fuel and combustion air to the burning zone is readily varied to respond
5 to any changes in the composition of the combustion-supporting gas and the hydrocarbon feed to the partial-combustion zone so that suitable temperatures are always maintained in the partial combustion zone.

The reasons for which soot forms in connection
10 with conventional partial combustion processes even when operated at properly elevated temperatures are not fully understood. It is suggested that perhaps the hot reactants from the flame combustion are rapidly cooled after leaving the flame zone either by expansion of the hot gases
15 in space or by contact with the relatively cold walls of the partial combustion chamber or both. Cooling to temperatures in the soot-formation range by these effects might explain the phenomenon. Such an explanation is also consistent with the substantially soot-free operation of
20 the invention where indirect heating of the partial combustion zone maintains it and its surrounding walls at temperatures equal to or greater than the desired partial combustion temperature. The hot walls surrounding the partial combustion zone may also promote surface combustion of
25 the hydrocarbon feed and thereby lessen carbon formation. Irrespective of the reasons which may explain the advantages obtained by indirect heat exchange in accordance with the invention, its operation does permit efficient conversion of hydrocarbons to hydrogen and carbon monoxide without
30 substantial soot formation.

The process of the invention can be conducted in

any suitable apparatus. The accompanying drawing illustrates diagrammatically one form of such apparatus. The drawing is provided for illustrative purposes and is not intended to limit the process. As seen in the drawing,

5 reference character 11 denotes a partial combustion zone separated by a heat transfer partition 12 from surrounding burning zone 13. The hydrocarbon feed and combustion-supporting gas, each preferably preheated, are separately injected through lines 14 and 16, respectively, into the

10 externally heated partial combustion zone 11. The physical dimensions and configuration of partial combustion zone 11 are such that the reactants flow at rates equal to or less than the rate of flame propagation and so that they as well as the products can be immediately raised

15 to and maintained at a temperature above about 2500°F. by heat transfer from the burning zone 13, thereby effecting substantially complete partial combustion without appreciable soot formation. As indicated, it is important that there be no substantial lag between the time when the reactants are introduced and admixed in the partial combustion zone and the time when they reach a temperature above

20 about 2500°F. Otherwise, the reaction proceeds in part with appreciable irreversible soot formation. Thus, for example, when a burner having a discharge nozzle, such as

25 is shown diagrammatically at 17 in the drawing, is used to introduce the reactants into the partial combustion zone, the burner nozzle or its tip is itself located within the externally heated partial combustion zone to insure that the reactants are rapidly heated to a suitable temperature.

30 The externally heated partial combustion zone must be of

sufficient size to give a minimum residence time of about 0.2 to about 0.5 second, also in order that the partial combustion reaction will proceed to substantial completion. Auxiliary fuel and air, each also preferably preheated, are introduced into burning zone 13 through lines 18 and 19 respectively, and are burned in such a way as to heat the entire partial combustion zone to maintain therein a temperature above about 2500°F. The pressure in partial combustion zone 11 is maintained at about 0 to about 500 psig, depending upon the pressure at which the product gas is desired. Where elevated pressures are maintained in the partial combustion zone 11, an equal pressure is preferably maintained in the burning zone 13 so that heat-transfer partition 12, already subjected to elevated temperature, need not be designed with sufficient thickness or strength to withstand substantial differential pressures. In practice, heat-transfer partition 12 is not constructed of metallic materials but of more refractory materials, such as ceramics, because of the elevated temperatures maintained. Consequently, to design such heat-transfer partitions with sufficient strength to withstand substantial differential pressures would result in uneconomically reduced rates of heat transfer from burning zone 13 to partial combustion zone 11. A pressure balance between the two zones can be conveniently achieved by bleeding a minor portion of the product gas from the partial combustion zone into the burning zone or by using appropriate pressure controls on the effluent gases of either of the two zones responsive to the pressure in the other of the two zones.

For efficient operation of the process of the

invention, certain amounts of preheat of the various feeds to the process are desirable. In the cases of the hydrocarbon feed to the partial combustion zone and the auxiliary fuel fired in the burning zone, preheat temperatures of about 300°F. to about 1000°F. are preferably used with best results obtained at the higher temperatures, provided, of course, that temperatures at which cracking or polymerization would take place are not exceeded in preheating.

Pure molecular oxygen supplied as combustion-supporting gas to the partial combustion zone is preferably preheated to a temperature of 300 to 1000°F. and steam or carbon dioxide, also as combustion-supporting gases, are preferably preheated to temperatures of 500 to 1600°F. For the air provided to the burning zone or in some cases to the partial combustion zone as combustion-supporting gas, a preheat temperature of 1000 to 1600°F. is preferably employed.

The thermal efficiency of the process can be increased by proper heat recovery from the effluents of both the partial combustion and burning zones. In this connection, the flue gas made in the burning zone has considerable available heating potential in view of the fact that it transfers heat to the partial combustion zone only at temperatures above about 2800°F. The flue gas is therefore profitably used, for example, prior to venting in generating steam and in preheating one or more of the feed streams to the process, as the air delivered to the burning zone. Similar heat recovery can be made from the products of the partial combustion zone provided, of course, that the products are desirably cooled before further use. One heat recovery arrangement is shown in the drawing. Hot flue gases

are recovered from burning zone 13 and passed through line 21 to a boiler 22 to which water is passed through line 23 and from which steam is withdrawn through line 24. The partly cooled flue gases from boiler 22 are further
5 cooled in heat exchanger 26 with air flowing in line 19, to preheat the air prior to its use in burning zone 13. It should be apparent that when partial combustion zone 11 and burning zone 13 are arranged in a furnace structure, for example, heat recovery from the flue gases can be
10 conveniently achieved by providing a flue gas exhaust section in the furnace with suitable heating coils disposed therein through which the water, air, or other fluids being preheated can be passed.

In a process for the direct reduction of iron
15 ore operating at about 30 psig and 2000°F., for example, the partial combustion of hydrocarbons is conducted by the present process in a partial combustion zone maintained at a pressure of about 35 psig and at about 2600°F., the product hydrogen and carbon monoxide are cooled to about 2000°F,
20 by indirect heat exchange generating steam, and the cooled products are passed to the direct iron ore reduction process as the required reducing gas.

In the accompanying tabulation, data are given for five specific examples in which hydrocarbon oils of various
25 compositions are gasified with combustion-supporting gases of various compositions in an externally heated partial combustion zone to produce hydrogen and carbon monoxide substantially free of soot. In each example, the same oil is used for gasification in the partial combustion zone and
30 for external heating in the burning zone. Preheat

temperatures throughout, where applicable, are: oil, 300°F.; oxygen, 800°F.; steam, 1520°F.; carbon dioxide, 1520°F.; air, 1520°F.

5 In each of the examples, the partial combustion zone is maintained at atmospheric pressure and at a temperature of 2690°F. by heat transfer from the burning zone from which flue gas is recovered at 3000°F. 25 percent excess air is used in the burning zone in each of the five examples.

10 In examples 1-4, pure oxygen provides the molecular oxygen in the combustion-supporting gas introduced into the partial combustion zone so that the product gas, in each case, is suitable, for example, for direct use in the reduction of iron ore to sponge iron. In example 5, pure
15 oxygen is replaced by air in such a proportion as to make the product gas, upon shift conversion, a suitable ammonia synthesis gas.

	<u>1</u> *	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
H ₂ /C, mols, oil feed to partial combustion zone	0.75862	1.05354	1.20515	1.47742	1.45809
O ₂ /oil, wt., feed to partial combustion zone	0.8548	0.8407	0.6690	0.3607	0.4675**
CO ₂ /oil, wt., feed to partial combustion zone	0.880	-	-	-	-
H ₂ O/oil, wt., feed to partial combustion zone	-	0.3603	0.5536	0.9008	0.8761
Product Gas Composition, mol %					
CO	62.51	48.45	45.14	40.21	30.34
CO ₂	0.19	0.25	0.21	0.15	0.49
H ₂	36.83	50.33	53.72	58.78	42.35
H ₂ O	0.43	0.97	0.93	0.86	2.59
N ₂	0.02	-	-	-	24.23
CO/H ₂	1.6973	0.9626	0.8403	0.6841	0.7163
Heat of Reaction	Slightly exothermic	Slightly exothermic	Isenthalpic	Slightly exothermic	Slightly exothermic
External Heating Requirement, Btu/1000 SCF CO H ₂	27.890	23.280	41.920	70.808	69.780
Consumption, lbs./1000 SCF H ₂ + CO					
Oil (Partial Combustion Zone)	18.04	18.40	16.93	15.22	15.83
Oil (Burning Zone)	3.84	3.37	6.06	10.23	10.08
100% O ₂	15.42	15.47	11.33	5.49	-**
CO ₂	15.86	-	-	-	-
H ₂ O	-	6.63	9.37	13.71	14.15

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* Product gas also contains 0.02 mol % H₂S

**Oxygen introduced as air

In example 1, the combustion-supporting gas consists of pure oxygen and carbon dioxide. A relatively high CO/H₂ ratio is obtained in the product gas by using carbon dioxide to supply a portion of the total oxygen requirement of the partial combustion reaction. The total oxygen supplied as oxygen and carbon dioxide to the partial combustion zone constitutes a one percent excess over the stoichiometric total oxygen requirement for converting the oil introduced into the partial combustion zone to hydrogen and carbon monoxide.

The combustion-supporting gases used in examples 2-4 each consist of pure oxygen and steam and each provide a 2.5 percent excess in total oxygen over the stoichiometric requirement. As is seen from the tabulated data, the use of steam to supply a portion of the total oxygen requirement leads to relatively low CO/H₂ ratios in the product gas, the value of this ratio decreasing as the proportion of steam in the combustion-supporting gas rises.

In the case of example 5, the combustion-supporting gas supplied to the partial combustion zone is a mixture consisting of steam and air which together provide a ten percent excess in total oxygen over the stoichiometric total oxygen requirement of the oil gasification occurring in the partial combustion zone.

The examples as a group represent partial combustion reactions which are slightly exothermic, isenthalpic and slightly endothermic. It is noted that even in examples 1 and 2 where the reactions in the partial combustion zone are slightly exothermic, there is an appreciable external heating requirement in order to maintain the partial combustion zone at 2690°F. at which temperature the reaction goes to completion without soot formation.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A process for the production of hydrogen and carbon monoxide which comprises introducing a hydrocarbon feed and a combustion-supporting gas into an externally heated partial combustion-zone maintained at a temperature above about 2500°F. by burning an auxiliary fuel at a higher temperature in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone, said combustion-supporting gas containing sufficient total oxygen to satisfy the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed to hydrogen and carbon monoxide, and recovering hydrogen and carbon monoxide from said partial combustion zone.

2. A process for the production of hydrogen and carbon monoxide which comprises introducing a hydrocarbon feed and a combustion-supporting gas into a partial combustion zone, said combustion-supporting gas containing sufficient total oxygen to satisfy the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed to hydrogen and carbon monoxide, firing an auxiliary fuel with air in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone, recovering hydrogen and carbon monoxide from said partial combustion zone at a temperature above about 2500°F. and separately recovering flue gases from said burning zone at

a higher temperature.

3. A process for the production of hydrogen and carbon monoxide which comprises introducing a hydrocarbon feed and a combustion-supporting gas into an externally heated partial combustion zone maintained at a temperature above about 2500°F. by burning an auxiliary fuel with air at a higher temperature in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone, said combustion-supporting gas containing between 0 and about 10 percent total oxygen in excess of the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed to hydrogen and carbon monoxide, and recovering hydrogen and carbon monoxide from said partial combustion zone.

4. A process for the production of hydrogen and carbon monoxide which comprises introducing a hydrocarbon feed and a combustion-supporting gas into an externally heated partial combustion zone maintained at a temperature above about 2500°F. by burning an auxiliary fuel with air at a higher temperature in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone, said combustion-supporting gas containing between about 2 and about 5 percent total oxygen in excess of the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed to hydrogen and carbon monoxide, and recovering hydrogen and carbon monoxide from said partial combustion zone.

5. A process for the production of hydrogen and carbon monoxide which comprises introducing a hydrocarbon feed and a combustion-supporting gas into a partial

combustion zone, said combustion-supporting gas providing between about 0.35 and about 1.30 pounds of molecular oxygen per pound of said hydrocarbon feed and containing sufficient total oxygen to satisfy the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed to hydrogen and carbon monoxide, firing an auxiliary fuel with air in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone, recovering hydrogen and carbon monoxide from said partial combustion zone at a temperature above about 2500°F. and separately recovering flue gases from said burning zone at a higher temperature.

6. A process for the production of hydrogen and carbon monoxide which comprises introducing a hydrocarbon feed and sufficient molecular oxygen to satisfy the stoichiometry of the partial combustion of said hydrocarbon feed to hydrogen and carbon monoxide into an externally heated partial combustion zone maintained at a temperature above about 2500°F. by burning an auxiliary fuel with air at a higher temperature in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone and recovering hydrogen and carbon monoxide from said partial combustion zone.

7. A process for the production of hydrogen and carbon monoxide which comprises introducing a hydrocarbon feed and a combustion-supporting gas into a partial combustion zone maintained at a pressure between about 0 and about 500 psig, said combustion-supporting gas containing sufficient total oxygen to satisfy the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed

to hydrogen and carbon monoxide, firing an auxiliary fuel with air in a burning zone maintained at a pressure substantially the same as that maintained in said partial combustion zone, said partial combustion zone and said burning zone being maintained in indirect heat exchanging relationship with one another, recovering hydrogen and carbon monoxide from said partial combustion zone at a temperature between about 2500°F. and about 3000°F. and separately recovering flue gases from said burning zone at a temperature between about 200 and 500°F. higher than said temperature in said partial combustion zone.

8. A process for the production of hydrogen and carbon monoxide which comprises introducing a preheated hydrocarbon feed and a preheated combustion-supporting gas into a partial combustion zone, said preheated combustion-supporting gas containing sufficient total oxygen to satisfy the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed to hydrogen and carbon monoxide, firing an auxiliary fuel with air in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone, recovering hydrogen and carbon monoxide from said partial combustion zone at a temperature above about 2500°F., separately recovering flue gases from said burning zone at a temperature between about 200 and 500°F. higher than said temperature in said partial combustion zone, and passing at least a portion of said recovered flue gases in indirect heat exchange with at least a portion of said combustion-supporting gas prior to its introduction to said partial combustion zone, thereby at least partly preheating said combustion-supporting gas.

9. In a process for producing sponge iron by

contacting iron oxide in a conversion zone with reducing gas rich in carbon monoxide and hydrogen at elevated temperatures, the method of producing said reducing gas which comprises introducing a hydrocarbon feed and a combustion-supporting gas into a partial combustion zone, said combustion-supporting gas containing sufficient total oxygen to satisfy the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed to hydrogen and carbon monoxide, firing an auxiliary fuel with air in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone, recovering the products of said partial combustion zone at a temperature above about 2500°F., separately recovering flue gases from said burning zone at a higher temperature, and passing said products of said partial combustion zone to said conversion zone to supply said reducing gas.

10. A process for producing ammonia synthesis gas which comprises introducing a hydrocarbon feed and a combustion-supporting gas into an externally heated partial combustion zone maintained at a temperature above about 2500°F. by burning an auxiliary fuel at a higher temperature in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone, said combustion-supporting gas containing sufficient air to provide the nitrogen requirement of subsequent ammonia synthesis and sufficient total oxygen to satisfy the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed to hydrogen and carbon monoxide, recovering the products of said partial combustion zone and subjecting them to shift conversion to produce a gas containing a molar ratio

of hydrogen to nitrogen of about three.

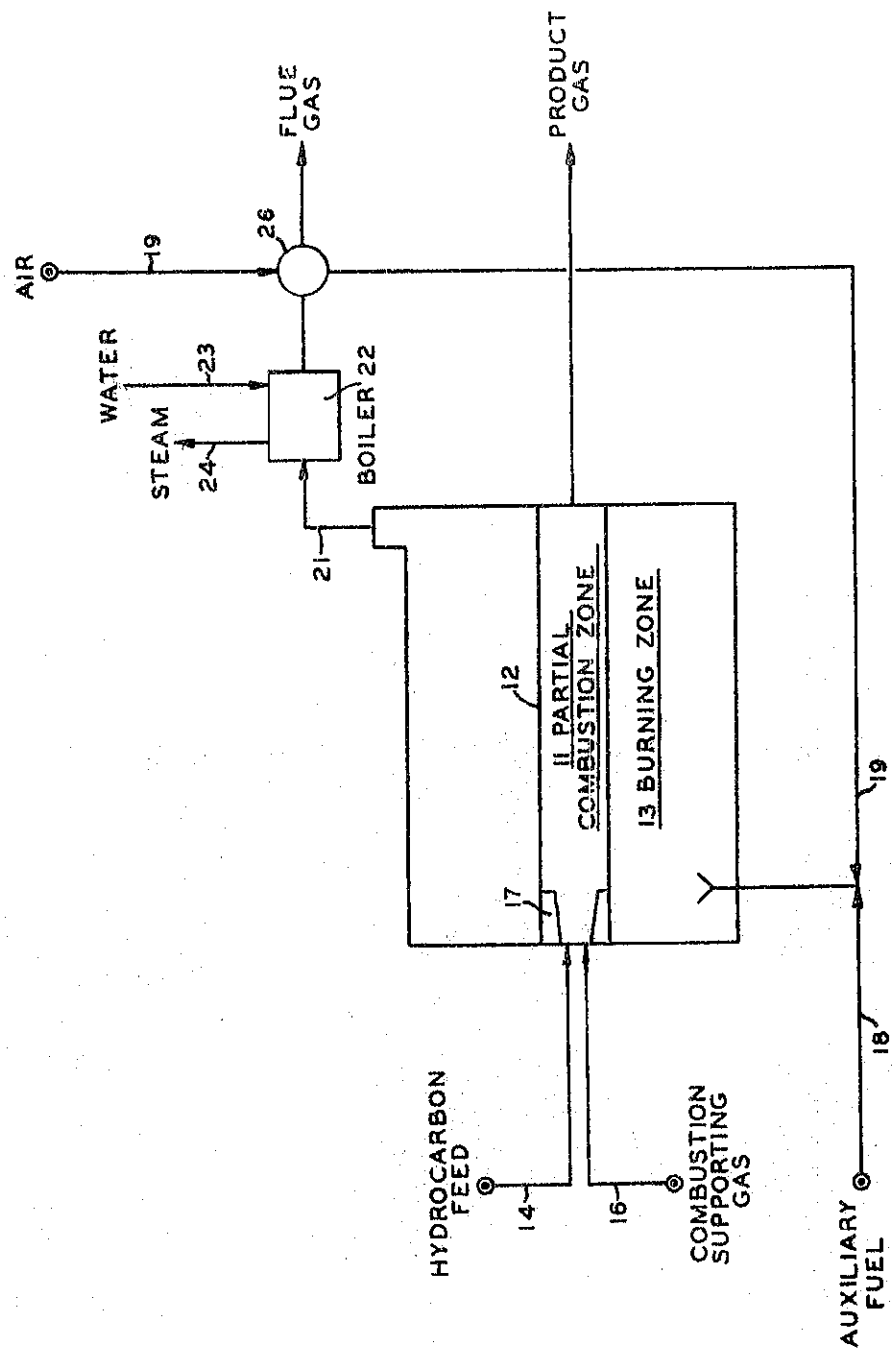
11. A process for producing ammonia synthesis gas which comprises introducing a hydrocarbon feed and a combustion-supporting gas into a partial combustion zone, said combustion-supporting gas consisting of air and steam in amounts sufficient to provide the nitrogen requirement of subsequent ammonia synthesis and the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed to hydrogen and carbon monoxide, firing an auxiliary fuel with air in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone, recovering the products of said partial combustion zone at a temperature above about 2500°F., separately recovering flue gases from said burning zone at a higher temperature, and subjecting said products of said partial combustion zone to shift conversion to produce a gas containing a molar ratio of hydrogen to nitrogen of about three.

12. A process for the production of hydrogen and carbon monoxide which comprises introducing a normally gaseous hydrocarbon feed and a combustion-supporting gas into an externally heated partial combustion zone maintained at a temperature above about 2500°F. by burning an auxiliary fuel with air at a higher temperature in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone, said combustion-supporting gas providing between about 0.90 and about 1.30 pounds of molecular oxygen per pound of said hydrocarbon feed and containing sufficient total oxygen to satisfy the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed to hydrogen and carbon monoxide and recovering hydrogen and

carbon monoxide from said partial combustion zone.

13. A process for the production of hydrogen and carbon monoxide which comprises introducing a normally liquid hydrocarbon feed and a combustion-supporting gas into an externally heated partial combustion zone maintained at a temperature above about 2500°F. by burning an auxiliary fuel with air at a higher temperature in a burning zone maintained in indirect heat exchanging relationship with said partial combustion zone, said combustion-supporting gas providing between about 0.35 and about 0.90 pounds of molecular oxygen per pound of said hydrocarbon feed and containing sufficient total oxygen to satisfy the stoichiometric total oxygen requirement for conversion of said hydrocarbon feed to hydrogen and carbon monoxide and recovering hydrogen and carbon monoxide from said partial combustion zone.





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