

Feb. 26, 1935.

G. A. DAVIS

1,992,909

PROCESS FOR REFORMING GASES

Filed Dec. 23, 1931

2 Sheets-Sheet 1

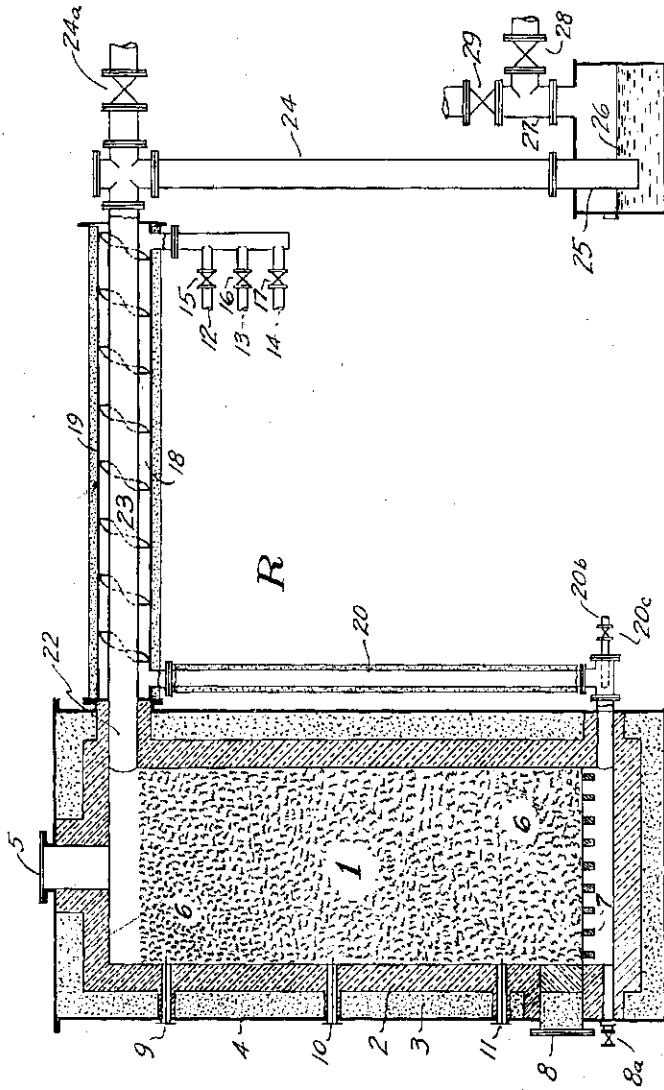


Fig. 1.

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2 Sheets-Sheet 2

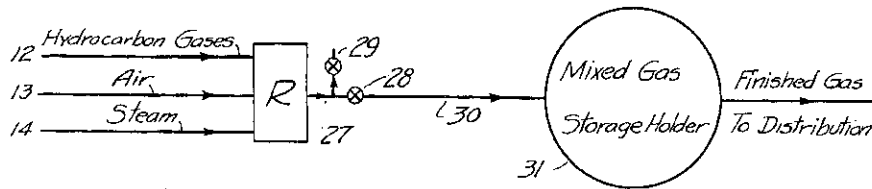


Fig. 2.

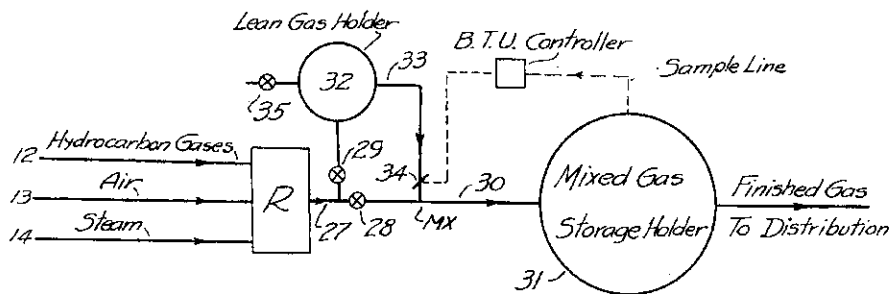


Fig. 3.

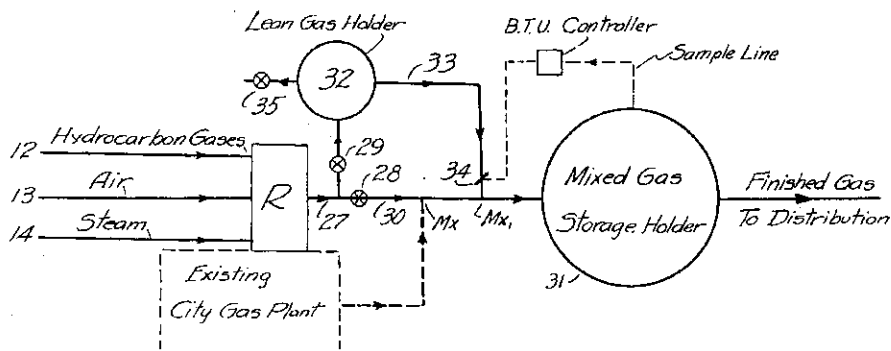


Fig. 4.

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1,992,909

PROCESS FOR REFORMING GASES

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Application December 28, 1931, Serial No. 583,502

10 Claims. (Cl. 48—196)

This invention particularly relates to the reforming of certain hydrocarbon gases, such as ordinary natural gases, commercial propane, commercial butane, and oil cracking still gases,—either separately in a substantially pure state, or in various mixtures thereof,—into reformed fixed combustible gases suitable for use in standard or existing domestic burners without requiring any changes in the burners or adjustment thereof, which reformed gases are interchangeable as to use in said burners with the present day standard city gases manufactured for domestic use.

Typical manufactured city gases are: retort coal gas and carburetted water gas. Such manufactured gases and also various essentially hydrocarbon gases have all found widespread use in domestic and industrial application. However, when the essential hydrocarbon gases are applied—in their natural or original state—in domestic burning appliances it is well known that they are not interchangeable with said manufactured city gas because of the different characteristics or properties thereof. While all of these gases have had a fairly widespread use, nevertheless, the cost of transportation heretofore confined the use of certain essential hydrocarbon gases to localized areas.

Refinements recently adopted in the petroleum industry have made the various hydrocarbon gases available in large quantities; and also recent improvements in transportation facilities have permitted the widespread distribution of such gases.

However, the widespread utilization of these hydrocarbon gases in the gas industry has heretofore been limited by their dissimilar properties as compared with standard manufactured city gases. Dissimilar gases are not mutually interchangeable on standard gas appliances without corresponding changes in design and adjustment of such appliances. Any gas appliance is designed and adjusted for the specific gas to be used. The chief properties of gas which influence the appliance design are:

- (a) Heating value.
- (b) Specific gravity.
- (c) Rate of flame propagation.

The tolerance range for any of the above mentioned properties is limited. As a general proposition for efficient operation of an appliance, the heating value of a gas should not deviate more than 5 to 10% from that which the appliance is designed for; the specific gravity should deviate

not more than 10–20% and rate of flame propagation should be as nearly constant as possible. A comparison of the properties of the several hydrocarbon gases and standard manufactured gas is as follows:—

	Heating value B. t. u./cu. ft.	Specific gravity	Rate of flame propagation
Typical std. mfg. city gas.	530–550	.60–.65	High
Typical natural gas.....	1000–1200	.60–.70	Low
Oil cracking still gas.....	1200–2000	.80–1.10	Medium to low
Propane.....	2800	1.52	Low
Butane.....	3200	2.00	Low

It is evident from the above comparison of the properties of various gases, that the hydrocarbon gases are not interchangeable with standard manufactured city gas for use in a given appliance without radical changes in design and adjustment, even though such interchangeability might be economically desirable.

More specifically certain objects of the invention herein described are as follows:—

(1) To convert or reform hydrocarbon gases to meet predetermined specifications relative to (a) heating value, (b) specific gravity, and (c) rate of flame propagation, so that the reformed gas is suitable for distribution in manufactured city gas systems without altering the design or adjustment of appliances.

(2) To utilize economically, the hydrocarbon gases, from natural gas fields and oil cracking plants, which are so frequently wasted.

(3) To provide a flexible process and means of producing a reformed gas to meet standard city gas specifications, from gaseous hydrocarbons by completely converting same at high thermal efficiency and without formation of liquid products or carbon residue.

(4) To provide a process for converting gaseous hydrocarbons to meet standard city gas requirements without the use of solid fuel such as coke or coal.

(5) To provide a simple means whereby the reforming of hydrocarbon gases according to my new process is enabled to be carried out in existing manufactured city gas equipment.

For the purpose of this invention the expression "hydrocarbon gases", or the expression "essentially hydrocarbon gases" is to be construed as covering a single natural gas, such as methane, ethane, propane, butane, or oil cracking still gas, or any gaseous substance or composi-

tion which includes in the main any one, two, or more of these gases.

According to one manner of realizing the invention the invention is carried out in a cycle the operation of which comprehends the combination of three distinct steps consecutively carried out namely as follows—assuming the gas reforming apparatus is in normal operation:—

(1) The decomposition step wherein hydrocarbon gases are decomposed or reacted upon into gases of lighter specific gravity accompanied by a deposition of free carbon—during this step there is a consequent cooling of the reforming chamber to the minimum temperature for the cycle.

(2) The air blowing step wherein some but not all of the deposited carbon is converted,—due to partial combustion, into producer gas—during this stage there is a consequent heating of the reforming chamber to the maximum temperature for the cycle.

(3) The steam injection step wherein the remaining carbon and introduced steam react to produce water gas—during this step there is a consequent cooling of the reforming chamber to an intermediate temperature for the cycle.

DECOMPOSITION STEP

Step 1.—In this step the hydrocarbon gases are passed into the gas reforming chamber (previously heated to the required temperature) wherein they are partially decomposed or reacted upon in the presence of catalyst preferably containing nickel. The extent of the decomposition depends upon the temperature, the rate of thrupt and the character of the catalyst. The products of decomposition are (1) a gas, composed largely of hydrogen, methane, and undecomposed hydrocarbon, which passes out of the reformer and is subsequently recovered; and (2) free carbon, substantially all of which is retained on the surface of the catalyst. This reaction is endothermic, causing the reformer temperature to drop 50°–300° F. below the initial temperature of this step.

AIR BLOWING STEP

Step 2.—In this step the reformer is purged with air to serve two purposes: first, part of the carbon deposited on the catalyst during Step 1 is converted to producer gas; and second, as a consequence of the exothermic nature of the reaction the temperature of the reformer is raised 50°–600° F. above the initial temperature of this step. The producer gas formed passes out of the reformer and as desired part or all is subsequently recovered.

STEAM INJECTION STEP

Step 3.—In this step steam is passed into the reformer, where it breaks up and combines or reacts with the balance of the carbon present to produce water gas. This reaction is endothermic, causing the reformer temperature to drop 50°–300° F. below the initial temperature of this step. The water gas produced passes out of the reformer, and is subsequently recovered.

The three steps above described constitute a complete cycle; and the cycles are repeated.

All of the gases produced and recovered during the decomposition stage are mixed with all or part of the gases produced and recovered during the air blowing step and also with all or part of the gases produced and recovered during the steam injection step; the resulting mixture constituting the "reformed" gases.

The initial temperature of the cycle, and the

rate of thrupt and duration of the respective stages are determined by the specifications of the reformed gas desired. As an example of the application of my process for the manufacture of a reformed gas having a heating value of 550 B. t. u. per cu. ft. and a specific gravity of .62 from a commercial butane I cite the following cycle schedule:—

Per. cu. ft. of 550 B. t. u. reformed gas:—

Step 1		
Average.....	Cu. ft. of gas made	.548
	Analysis:—C ₄ H ₁₀	3.0%
	H ₂	68.0
	C ₂ H ₆	29.0
Max. temp. 1300° F.....	+2	
Min. temp. 1175° F.....	B. t. u. per cu. ft.....	865.
	Sp. gr.....	.495
Step 2		
Average.....	Cu. ft. of gas made	.920
	Analysis:—CO ₂	14.0%
	CO	11.4
	N ₂	74.6
Max. temp. 1450° F.....	B. t. u. per cu. ft.....	36.3
Min. temp. 1175° F.....	Sp. gr.....	1.048
Step 3		
Average.....	Cu. ft. of gas made	.242
	Analysis:—CO ₂	12.0%
	H ₂	56.0
	CO	32.0
	CH ₄	Trace.
Max. temp. 1450° F.....	B. t. u. per cu. ft.....	282.
Min. temp. 1300° F.....	Sp. gr.....	.531

Of the .920 cu. ft. of gas recovered during Step 2, .210 cu. ft. is used in the mixed gas, and the balance purged to the atmosphere, or utilized in waste heat boilers.

HEAT BALANCE

Input.—(Heat of combustion of butane) ..	100%
Output	
Heat of combustion of mixed reformed gas	89.5%
Heat of combustion of gas purged.....	4.2
Sensible heat loss.....	5.3
Radiation	1.0
Total output.....	100.0%

The invention, however, according to certain aspects thereof, is not limited to the above cycle described, wherein the three steps are carried out separately. It is also possible to produce reformed gases of various compositions by employing other schedules of operation as follows:—

(1) Any two of the steps may be jointly carried out, e. g. air and hydrocarbon gas may be passed into the reformer simultaneously, thus combining steps (1) and (2).

(2) With the nickel catalyst all three steps may be simultaneously carried out and certain advantageous results realized.

(3) Any one of the three steps may be jointly carried out, with part of any other step, e. g. part of the volume of air used may be passed into the reformer with the hydrocarbon gas, the balance of the volume of air required being passed in separately.

(4) Any two of the steps may be jointly carried out with part of the third step, e. g. the steam, hydrocarbon gas, and part of the volume of air used may be passed into the generator at the same time, the balance of the air being passed in separately.

As illustrative of certain manners in which the invention may be realized and employed reference is made to the drawings forming part of this specification and in which drawings;

5 Figure 1 is an elevation partly in vertical section showing the general arrangement of the gas reformer. The gas reformer as shown in said Figure 1 is an apparatus having suitable piping connections and a gas reforming or reacting chamber filled with a catalytic substance, preferably pure nickel wire in the form of helical springs.

15 Figure 2 is a diagram of a system employing the reformer of Figure 1 but according to the arrangement of Figure 2 the gases produced, as from each step of the reformer, are passed into a storage holder and therein blended.

20 Figure 3 is a diagram of a system employing the reformer of Figure 1 but according to the arrangement of Figure 3 the gases produced in the reformer, as during operating Steps 1 and 3 of the reformer, are passed into a storage holder; and the gases produced as during operating Step 2 of the reformer, are passed to a lean gas relief holder, and therefrom by means of a B. t. u. controller to the storage holder in the proper quantity to maintain constant the heating value of the mixed gases in the storage holder.

30 Figure 4 is a diagram of a system employing the reformer of Figure 1 but according to the arrangement of Figure 4 a system, such as shown in Figure 3, has been adapted to an existing manufactured gas plant whereby the reformed gases produced as from Steps 1 and 3 of the reformer are caused to pass into the general storage holder with the existing manufactured gas, and whereby the gases produced as from Step 2 of the reformer are caused to pass into the lean gas holder and therefrom by means of a B. t. u. controller into the storage holder wherein the gases from the lean gas holder are admixed in predetermined proportions with the gases in the storage holder to maintain a constant B. t. u. of such mixed gases.

45 It will be here noted that Figures 2, 3 and 4 illustrate diagrammatically how the gas reformer of Figure 1 and the reformed gases therefrom can be commercially employed. Therefore, the construction of the gas reformer of Figures 1-4 inclusive, mode of operation, the process carried out therein and the type of product produced thereby and therein will be described fully in detail before further reference is made to the arrangement and functioning of the system or plant of Figures 2, 3 and 4. Reference will now be made to the drawings in detail.

GAS REFORMER—FIGURE 1

60 The gas reformer or gas reforming apparatus, as a gas reforming system as a whole may be referred to, is herein designated by R. It includes the gas reforming or reacting chamber 1 which is provided with a refractory lining 2 surrounded with heat insulating material as 3. The gas reforming chamber is provided with a gas-tight metallic casing or shell 4 having a charging door 5 for charging the catalytic mass 6 which is supported by grate bars 7 discharging door 8 for removing the catalytic mass when necessary.

75 The catalyst while preferably of pure nickel wire in the form of helical springs may also be of nickel in other forms such as scrap, strips,

bars, etc., or nickel clad steel, or refractory material impregnated with reduced nickel (according to any of the several methods well known to the art). The catalyst may also be of other metals such as steel, cobalt, etc., although experimental tests indicate a decided advantage in favor of nickel over the several other materials tested. In other words, according to one definition the catalyst may comprise, contain, or consist of a metal or metals of the ferrous group.

5 Suitable pyrometer connections are provided at 9, 10, and 11. The hydrocarbon gas, air, and steam supply lines are shown at 12, 13, and 14 respectively, with respective control valves 15, 16 and 17. The hydrocarbon gas, air, and steam as required by the particular operating schedule pass thru the annular space 18 of the heat exchanger 19, thru connecting line 20 and thence to the base of the reformer, thence thru the catalytic mass 6 where the reforming takes place 20 in the presence of the catalytic mass. The resulting hot reformed gases pass from the reformer through off-take 22 to inner space 23 of the heat exchanger to connecting pipe 24 provided with stack valve 24a to dip pipe 25 and thru water seal 26 to outlet 27 and thence to mixing system thru valve 28 or 29 depending upon cycle of operation as hereinafter described in Figures 2, 3, and 4.

30 To start up the gas reformer or the gas reforming apparatus, as the gas reforming system as a whole may be referred to, hydrocarbon gases are fed through conduit 12 thru heat exchanger 18 to conduit 20 into bottom of the reforming chamber 1. Air is simultaneously admitted thru conduit 20b thru valve 20c to bottom of the reformer, in such proportion as to produce nearly complete combustion when the mixture of air and hydrocarbon gas is ignited, as by torch flame inserted thru port 8a. The resulting combustion quickly brings the reforming chamber to the required temperature. The combustion products are conducted from the reformer thru the heat exchanger 23 and allowed to escape thru the relief or stack valve 24a to the atmosphere. When the desired temperature of the reforming chamber is attained, as for example 1300° F., and which temperature for certain gases and conditions is a normal temperature,—then the air supply from 20b is discontinued, by closing valves 20c and 24a; and the first step of the reforming cycle is started. Hydrocarbon gases at the proper rate continue to flow thru the reformer wherein, in the presence of the catalyst, decomposition or reaction takes place. The products of this decomposition or reaction are free carbon and lighter fixed gases. Substantially all of the free carbon produced is retained on the surface of the catalyst. The gases resulting from said decomposition pass from the reformer thru heat exchanger 23 (thus preheating the incoming hydrocarbon gases) to conduit 24 and thru the water seal 26 and are subsequently recovered in the mixing system hereinafter described. When the temperature of the reformer lowers to the predetermined point, the operation of this Step (1) is terminated by closing valve 15. The reformer is now ready for operation of Step (2) as heretofore described. Valve 16 is opened and air is passed under suitable pressure thru the heat exchanger space 18 to conduit 20 into the bottom of the reformer chamber and in contact with the hot carbon deposited on the catalyst during Step 1. The oxygen from the air thus injected converts part of the de- 75

posited carbon to producer gas and at the same time raises the temperature of the reforming chamber due to the exothermic nature of the producer gas reaction. The resulting gas produced during this step is conducted thru the heat exchanger space 23 to seal 26 in the same manner as above described in Step (1) and subsequently recovered in the mixing means hereinafter described. When the proper predetermined temperature of the reforming chamber is reached the operation of Step 2 is terminated by closing valve 16 and the reformer is ready for Step (3) as heretofore described wherein valve 17 is opened and steam is passed into the reforming chamber in like manner as Steps (1) and (2) thru heat exchanger space 18 where it is superheated before delivering to the reforming chamber by means of conduit 20. The superheated steam is passed thru the reformer in contact with the remainder of the hot carbon on the surface of the catalyst whereby the steam is decomposed by reaction with the hot carbon, to water gas. The temperature of the reformer is lowered because of the endothermic nature of the reaction. The resulting water gas passes from the reformer thru heat exchanger space 23, thus superheating the incoming steam, to seal 26 in the same manner as above described in Steps (1) and (2) and subsequently recovered in the mixing means hereinafter described—when the proper predetermined minimum temperature of the reforming chamber is attained, the operation of Step (3) is terminated by closing valve 17 thus completing the cycle.

By way of example when the gas reformer is in normal operation the temperature within the reforming chamber is above 1000° F., varying thru-out the cycle in accordance with the various endothermic and exothermic reactions which occur within the reforming chamber during the cycle. The variations in temperature are limited by the thermal capacity of the reforming chamber contents (catalytic mass, and any inert material such as refractory checker brick which may have been inserted for the purpose of increasing the thermal capacity).

The hydrocarbon gases, steam and air flowing to the reformer, are preheated by the gases leaving the reformer by means of heat exchangers associated with the off-take piping and water seal.

SYSTEMS OR PLANTS OF FIGURES 2, 3, AND 4

Each of the systems of Figures 2, 3 and 4 employs a gas reforming process such as fully described in connection with Figure 1, and the gas reformer R of each of the Figures 2, 3 and 4 is the same in essentials of construction, function, and mode of operation as the gas reformer shown and fully described in connection with Figure 1.

System of Figure 2

This Figure 2 illustrates diagrammatically a system whereby hydrocarbon gases, air, and steam, are supplied thru lines 12, 13 and 14 respectively to the reformer R and treated or reformed in a manner previously described in respect to Figure 1, and the resulting reformed gases produced from the complete reforming cycle are conducted thru line 27—having bleed valve 29 normally closed—thru valve 28 and line 30 to a storage holder 31 wherein the gases are thoroughly mixed by diffusion. The three steps are so proportioned in regard to temperatures, and thruput and duration of each stage that the

combined gases constituting the resulting mixed gases approximate the predetermined specifications. However, to exactly meet the predetermined specifications part of the gas made during Step 2 and/or Step 3 is purged to the atmosphere by means of valve 29.

System of Figure 3

This Figure 3 illustrates diagrammatically a reforming system whereby hydrocarbon gases, air, and steam are supplied thru lines 12, 13 and 14 respectively to reformer R and treated or reformed in a manner previously described in respect to Figure 1, and the resulting gases from Step (1) and Step (3) are conducted thru line 27 and valve 28 (valve on line 29 is closed) and thru line 30 to the storage holder 31. The gas produced during the reforming Step (2) is conducted thru line 27 thru valve on line 29, (valve 28 is closed) to the lean gas holder 32. The lean gas from holder 32 is conducted thru line 33 to a point MX at which point the lean gas is admitted to line 30 and conducted to the storage holder. The flow of the lean gas thru line 33 is automatically controlled by valve 34 to maintain a uniform B. t. u. per cu. ft. of the gas in the storage holder 31. Valve 34 is actuated by any well known B. t. u. (heating value) controller and which B. t. u. controller would receive a continuous sample of gas from the reformed gas holder and automatically varies the setting of valve 34 to maintain a constant heating value of the reformed gas in the storage holder for the specific (finished) gases desired from any complete cycle of operation. In the event that there is a surplus of lean gas from any cycle of operation, such gas may be conducted thru line 35 to any desired point, as for example, for use as fuel.

System of Figure 4

This Figure 4 illustrates diagrammatically a reforming system whereby hydrocarbon gas, air, and steam, are supplied thru lines 12, 13 and 14 respectively to reformer R and treated or reformed in a manner previously described in respect to Figure 1, and the resulting gases from Step (1) and Step (3) are conducted thru line 27 and valve 28 (valve on line 29 is closed) and thru line 30 to point MX on line 30, at which point the reformed gases mix with the manufactured gases produced from an existing gas plant, while flowing to and into the storage holder 31. The gas produced during the reforming Step (2) is conducted thru line 27 thru valve 29 (valve 28 is closed) to the lean gas holder 32. The lean gas from holder 32 is thereafter conducted thru line 33 to a point MX₁ in line 30, at which point the lean gas is mixed in the proper proportions with the gases flowing to and into the storage holder 31. The flow of the lean gas thru line 33 to point MX₁ is automatically controlled by valve 34 to maintain a uniform B. t. u. per cu. ft. of the gases in the storage holder 31. Valve 34 is actuated by any well known B. t. u. controller, and which B. t. u. controller receives a continuous sample of the gas from the storage holder and by nature of its operation automatically varies the setting of valve 34 (electrically operated) to allow proper volume of lean gas to flow to point MX₁ and thus maintain the desired quality of mixed gas in the storage holder. Any surplus of lean gas produced from any cycle of operation may be con-

ducted thru line 35 to any desired point for use as fuel.

The three step process as above particularly described, and the modification thereof as also above outlined, can be carried out in the gas reformer of Figure 1 and can also be employed in the various systems such as that shown in Figures 2, 3 and 4 which rely for their performance upon, and which include, gas reformer of Figure 1.

As previously indicated, the three step process can be materially modified and the modification will still be in the broad aspects of the invention. By way of further example, the following processes, namely the two step per cycle process, and the continuous process wherein all three steps are combined, are sufficiently described hereinafter. Moreover each of these processes can be readily performed in the reformer of Figure 1 and can also be employed in system of Figures 2, 3 and 4.

DESCRIPTION OF THE TWO-STEP PROCESS

The two step reformed gas process consists of a decomposition step and an air blowing (producer gas) step per cycle. In the decomposition Step (1) of the cycle, hydrocarbon gases are fed into the reforming chamber (previously heated to the required temperature) wherein they are decomposed or reacted upon preferably in the presence of a catalyst containing nickel. The products of the decomposition or reaction are (1) a gas, composed largely of hydrogen, methane, and undecomposed hydrocarbon gases, the resulting gases pass out of the reformer and are subsequently recovered; and (2) free carbon, substantially all of which is retained on the surface of the catalyst, and which catalyst thus serves to mechanically filter the free carbon as produced and prevent its passing out of the reformer in suspension with the gases. The reaction is endothermic, causing the reformer temperature to drop 50°-300° F. below the initial temperature of this step.

Upon completion of Step 1, the air blowing (producer gas) Step 2 is commenced wherein air is passed into the reformer to serve two purposes:—first, all of the carbon deposited in the catalyst during Step (1) is converted to producer gas; and second as a consequence of the exothermic nature of the reaction the temperature of the reformer is raised 50°-300° F. above the initial temperature of this step. The producer gas formed passes out of the reformer and as desired part or all is subsequently recovered.

The two steps above described constitute a complete cycle; and the cycles are repeated. All of the gases produced and recovered during the decomposition step are mixed with all or part of the gases produced during the air blowing (producer gas) step; the resulting mixture constituting the reformed gases, and which resulting reformed gases have a specific gravity between the range of .65 to .70 as compared with air, and a heating value between the range of 500-1000 B. t. u. per cu. ft.

DESCRIPTION OF THE CONTINUOUS (SINGLE STEP) PROCESS

In the continuous reforming process, all three steps of the three step process above described are simultaneously carried out as follows:—

A mixture of hydrocarbon gases, air and steam, in predetermined proportions, preferably preheated, are continuously fed into a hot reformer

having a temperature between the ranges of 1000°-1600° F., in contact with the hot catalytic mass. The proportion of air in the mixture is sufficient only to cause partial combustion of the hydrocarbon gases and to maintain constant the desired temperature of the reformer. The heat generated by the partial combustion, and the presence of the catalyst causes decomposition and reforming of the hydrocarbon gases and steam and the reaction is performed without the production of carbon residue. The resulting reformed gases as withdrawn from the reformer have a specific gravity between the range of .70-.80 and a heating value between the range of 400-700 B. t. u. per cu. ft. depending upon the proportion of air, steam, and hydrocarbon gases in the inflowing mixture.

In order to differentiate between the various processes as above described, namely the three step, two step, and the continuous (single step) process, the following data on the results obtained with each process is given as compared with standard manufactured city gas:—

Process/cycle	3 step	2 step	Contin- uous	Std. mfg. city gas
Heating value.....	500-1000	500-1000	400-700	530-550
Specific gravity.....	.60-.65	.65-.70	.70-.80	.60-.65

It is hereby pointed out that in any of the systems above described, it is possible to produce resulting finished gases, or a mixture of gases which may be termed finished gases that satisfy the requirements of standard manufactured city gases, and which can be used as a substitute for, or interchangeably with, varying grades of standard manufactured city gases and which finished gases are what may be referred to as combustible fixed gases.

The improvements herein set forth are not limited to the precise construction and arrangement shown and described for it will be appreciated that they may be realized in various forms, ways and modifications without departing from the spirit and scope of the invention.

What is claimed is:—

1. The manufacture from hydrocarbon gases of a combustible fixed gas by the method which includes three distinct steps per cycle, wherein according to Step (1) hydrocarbon gases are introduced into a reforming chamber, in contact with a hot catalytic mass containing nickel, and/or iron, and any carbon remaining which has been deposited as a result of the thermal decomposition of the hydrocarbon gases in the presence of said nickel and/or iron, having a temperature between the range of 1000°-1600° F., decomposing the hydrocarbon gases in the presence of the catalytic mass, into reformed gases and free carbon, retaining said free carbon in the reforming chamber, wherein according to Step (2) air is introduced into the reformer in contact with the hot carbon, and in the presence of the catalyst, thus converting a portion of said carbon into producer gas; and wherein according to Step (3) steam is introduced into the reforming chamber in contact with the remainder of the hot carbon, thus converting the carbon by reaction with the steam into water gas; said method also includes withdrawing in consecutive order, the resulting hot gases as produced from each step in a manner whereby heat is imparted therefrom to the inflowing hydrocarbon gas, air and

steam treated during each step, to preheat the latter; mixing the resulting gases produced from each step to produce a mixture of gases having properties substantially the same as standard manufactured city gas.

2. The manufacture from hydrocarbon gases of a combustible fixed gas by the method which includes three distinct steps per cycle, wherein according to Step (1) hydrocarbon gases are introduced into a reforming chamber, in contact with a hot catalytic mass having a temperature within the range of 1000 to 1600 degrees F., and which said catalytic mass comprises a metal or metals of the ferrous group and any carbon which has been deposited as a result of the thermal decomposition of the hydrocarbon gases in the presence of the catalytic mass, decomposing the hydrocarbon gases in the presence of the catalytic mass into reformed gases and free carbon, retaining said free carbon on the surface of the catalyst; wherein according to Step (2) air is introduced into the reformer in contact with the hot carbon retained on the catalyst, thus converting a portion of said carbon into producer gas; and wherein according to Step (3) steam is introduced into the reforming chamber in contact with the remainder of the hot carbon on the catalyst, thus converting said remaining hot carbon by reaction with the steam into water gas; said method also including withdrawing in consecutive order, the resulting hot gases as produced from each step in a manner whereby heat is imparted therefrom to the inflowing hydrocarbon gases, air, and steam treated during each step to preheat the latter.

3. The manufacture from hydrocarbon gases of a combustible fixed gas by the method which consists of three distinct steps per cycle, wherein during Step (1) hydrocarbon gases are introduced into a reforming chamber in contact with a hot catalytic mass having a temperature within the range of 1,000 to 1,600 degrees F., and which said catalytic mass contains a metal or metals of the ferrous group and any remaining carbon which has been deposited as a result of the thermal decomposition of the hydrocarbon gases in the presence of the catalytic mass, decomposing the hydrocarbon gases in the presence of the catalytic mass into reformed gases and free carbon, retaining said free carbon on the surface of the catalyst; wherein during Step (2) air is introduced into the reformer in contact with the hot carbon retained on the catalyst, thus converting a portion of said carbon into producer gas; and wherein during Step (3) steam is introduced into the reforming chamber, in contact with the remaining hot carbon, thus converting the carbon by reaction with the steam into water gas, and which cycle includes withdrawing in consecutive order, the resulting hot gases as produced from each step in a manner whereby heat is imparted therefrom to the inflowing material treated during each step, to preheat the latter.

4. The manufacture from hydrocarbon gases of a combustible fixed gas by the method which consists of three distinct steps per cycle, wherein during Step (1) hydrocarbon gases are introduced into a reforming chamber in contact with a hot catalytic mass having a temperature within the range of 1,000 to 1,600 degrees F., and which said catalytic mass contains a metal or metals of the ferrous group and any remaining carbon which has been deposited as a result of the thermal decomposition of the hydrocarbon gases in

the presence of the catalytic mass, decomposing the hydrocarbon gases in the presence of the catalytic mass into reformed gases and free carbon, retaining free carbon on the surface of the catalyst; wherein during Step (2) air is introduced into the reformer in contact with the hot carbon, thus converting a portion of said carbon into producer gas; and wherein during Step (3) steam is introduced into the reforming chamber in contact with the hot carbon, thus converting said remaining hot carbon by reaction with the steam, into water gas, and which cycle includes the withdrawing in consecutive order, the resulting hot gases as produced from each step.

5. The manufacture from hydrocarbon gases of a combustible fixed gas by the method which comprises three distinct steps per cycle of successive cycles wherein according to the first step of each cycle hydrocarbon gases and air are introduced simultaneously in predetermined proportions, into a reforming chamber, in contact with a hot catalytic mass at a temperature within the range of 1,000 to 1,600 degrees F., and which said catalytic mass comprises a metal or metals of the ferrous group and any remaining carbon which has been deposited as a result of the thermal decomposition of the hydrocarbon gases in the presence of the catalytic mass, decomposing or reacting the hydrocarbon gases in the presence of the catalyst into reformed gases and free carbon, retaining said free carbon on the surface of the catalyst; wherein according to the second step, air is introduced into the reformer in contact with the hot carbon retained on the surface of the catalyst, thus converting a portion of said carbon into producer gas; and wherein according to the third step, steam is introduced into the reforming chamber in contact with the remaining hot carbon on the catalyst, thus converting the said remaining hot carbon by reaction with the steam, into water gas, which method also comprises withdrawing in consecutive order during each cycle, the resulting hot gases as produced in the particular step whereby heat is imparted from the hot outflowing gases to the inflowing material treated during this particular step, to preheat the latter.

6. The manufacture from hydrocarbon gases of a combustible fixed gas by the method which comprises successive cycles in which there are three distinct steps per cycle and wherein during step one of the cycle, hydrocarbon gases and steam are introduced simultaneously in predetermined proportions, into a reforming chamber in contact with a hot catalytic mass at a temperature within the range of 1000 to 1600 degrees F., and which said catalytic mass comprises a metal or metals of the ferrous group and any remaining carbon which has been deposited as a result of the thermal decomposition of the hydrocarbon gases in the presence of the catalytic mass, decomposing or reacting the hydrocarbon gases and steam in the presence of the hot catalyst into reformed gases and free carbon and retaining free carbon in the presence of the catalyst; wherein during step two air is introduced into the reformer in contact with the hot carbon, thus converting a portion of said carbon into producer gas; and wherein during step three, steam is introduced into the reforming chamber in contact with the remainder of the hot carbon; thus converting the remaining hot carbon by reaction with the steam into water gas; withdrawing in consecutive order the

resulting hot gases produced from each step in a manner whereby heat is imparted therefrom to the inflowing material treated during each step of each successive cycle, to preheat the latter.

5 7. The manufacture from hydrocarbon gases of a combustible fixed gas by the method which comprises successive cycles in which there are three distinct steps per cycle and wherein during Step one of the cycle, hydrocarbon gases and steam
10 are introduced simultaneously in predetermined proportions, into a reforming chamber in contact with a hot catalytic mass at a temperature within the range of 1000 to 1600 degrees F., and which
15 said catalytic mass comprises a metal or metals of the ferrous group and any remaining carbon which has been deposited as a result of the thermal decomposition of the hydrocarbon gases in the presence of the catalytic mass, decomposing
20 or reacting the hydrocarbon gases and steam in the presence of the hot catalyst into reformed gases and free carbon and retaining free carbon in the presence of the catalyst; wherein during
25 Step two, air is introduced into the reformer in contact with the hot carbon, thus converting a portion of said carbon into producer gas; and wherein during Step three, steam is introduced into the reforming chamber in contact with the hot carbon; thus converting hot carbon by reaction with the steam into water gas; withdrawing
30 in consecutive order, the resulting hot gases as produced from each step.

8. The manufacture from hydrocarbon gases of a reformed combustible fixed gas by the method which includes two distinct steps per cycle, where-
35 in according to Step (1) hydrocarbon gases are introduced into a reforming chamber, in contact with a hot catalytic mass having a temperature within the range of 1000 to 1600 degrees F., and which said catalytic mass comprises a metal or
40 metals of the ferrous group and any remaining carbon which has been deposited as a result of the thermal decomposition of the hydrocarbon gases in the presence of the catalytic mass, decomposing or reacting the hydrocarbon gases in
45 the presence of the catalytic mass into reformed gases and free carbon, retaining free carbon in the presence of the catalyst; and wherein according to Step (2) air is introduced into the reformer in contact with the hot carbon, thus converting
50 said carbon into producer gas; said method also includes withdrawing in consecutive order, the resulting hot gases as produced from each step in a manner whereby heat is imparted therefrom to the inflowing hydrocarbon gases,

and air, treated during each step, to preheat the latter.

9. The manufacture from hydrocarbon gases of a reformed combustible fixed gas by the method which includes two distinct steps per cycle, where-
5 in according to Step (1) hydrocarbon gases are introduced into a reforming chamber, in contact with a hot catalytic mass having a temperature within the range of 1000 to 1600 degrees F., and which said catalytic mass comprises a metal or
10 metals of the ferrous group and any remaining carbon which has been deposited as a result of the decomposition of the hydrocarbon gases in the presence of the catalytic mass, decomposing or reacting the hydrocarbon gases in the presence
15 of the catalytic mass into reformed gases and free carbon, retaining said free carbon on the surface of the catalyst; and wherein according to Step (2) air is introduced into the reformer in contact with the hot carbon retained on the
20 catalyst, thus converting all of the said carbon into producer gas; said method also includes withdrawing in consecutive order, the resulting hot gases as produced from each step.

10. The manufacture from hydrocarbon gases
25 of a reformed combustible gas by the method which consists of continuously introducing a mixture of hydrocarbon gases, air, and steam in predetermined proportions, preferably preheated, into a reforming chamber, in contact with a hot
30 catalytic mass that comprises a metal or metals of the ferrous group and any remaining carbon which has been deposited as a result of the thermal decomposition of the hydrocarbon gases in the presence of the catalytic mass, at a tem-
35 perature between the ranges of 1000-1600° F., the proportion of air sufficient only to cause partial combustion of the hydrocarbon gases and maintain a constant temperature of the reforming chamber; decomposing and reforming the
40 hydrocarbon gases and steam in the presence of the catalyst, by the heat generated by said partial combustion; thus continuously producing without the formation of carbon residue, a reformed combustible fixed gas of lower calorific value per
45 unit of volume and a larger volume than the hydrocarbon gases from which it was produced; and continuously withdrawing the resulting gases from the reformer, said resulting gases having a specific gravity between the range of .70-.80, and
50 a heating value between the range of 400-700 B. t. u. per cubic foot.

GEORGE ALAN DAVIS.