

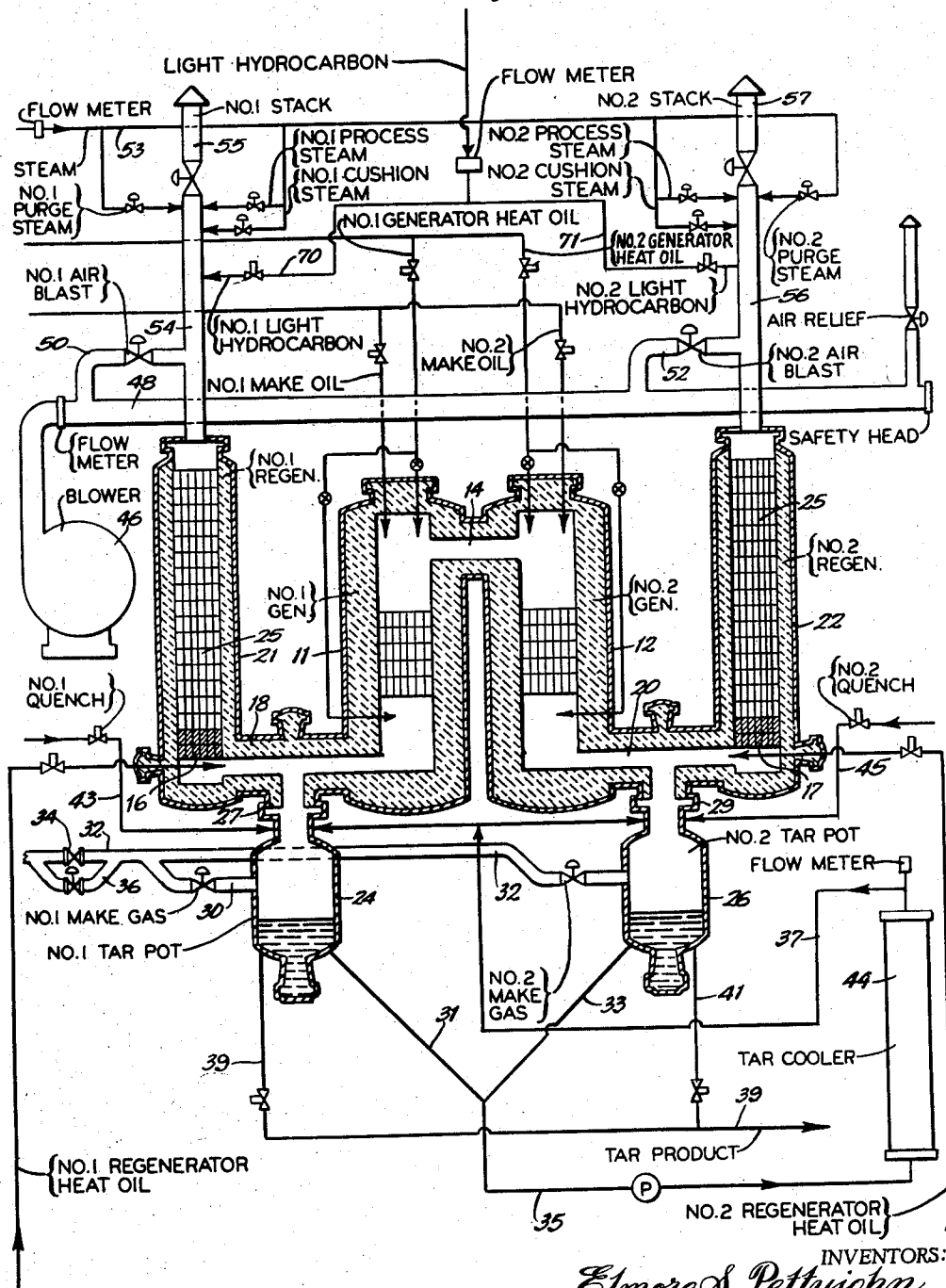
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CYCLIC REGENERATIVE PROCESS FOR MAKING FUEL GAS

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2,882,138

CYCLIC REGENERATIVE PROCESS FOR MAKING FUEL GAS

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This invention relates to a cyclic regenerative process for producing fuel gas from liquid or liquefiable fossil fuels ranging in molecular weight up to and including that of Bunker "C" fuel oil.

The present invention may be practiced in a cyclic regenerative apparatus of the type shown and described in our copending application Serial No. 424,012, now U.S. Patent 2,807,528, of which the present application is a continuation-in-part. Preferably, a four-shell set is used including a first and second generator communicating with a first and second regenerator, respectively.

In accordance with the prior art, the production of high B.t.u. oil gases from the lower-cost petroleum products characterized by low hydrogen content, high specific gravity and high coke-forming tendency during thermal cracking operations, such as Bunker "C" oil, results in a relatively low conversion to gas. Usually it ranges from 35% to 50%, with the remainder consisting primarily of tar, pitch and deposited coke. Even with better-grade oils, such as reduced crude oils and distillate fuel oils, conversions to gas do not normally exceed 50% to 60%. This results in low capacities of any given cyclic cracking installation and high investment costs. Added to these disadvantages are the high investment and operating costs for the tar handling and recovery equipment.

The gases produced in conventional cyclic cracking equipment are characterized by a high content of olefinic hydrocarbons and frequently a high content of inert combustion gases, which results in poor combustion characteristics when complete substitution for natural gas is attempted during periods of peak demand or failure of the natural gas supply. This is evidenced by a tendency to form luminous flames and to deposit soot, and a tendency for the flames to flash back upon ignition or turn off.

Improvements of these processes have been described in United States Patents No. 2,721,122, issued October 18, 1955, and No. 2,721,123, issued October 18, 1955, and in copending applications Serial No. 424,012, filed April 19, 1954, now Patent No. 2,807,528, and Serial No. 645,293, filed March 11, 1957. In these improvements of the cyclic oil gasification process it is shown that gases of improved combustion performance can be produced by the use of superatmospheric gasification pressures and of certain carrier gases, and that increased yields of gas can be obtained by the use of hydrogen-rich carrier gas.

One recommended method of supplying said hydrogen-rich carrier gas was the use of an external supply. The primary objective of this invention is to provide a method for producing hydrogen-rich carrier gas within the apparatus described in copending application Serial No. 424,012. In this novel process, the apparatus employed in the practice of the present invention has been modified from that shown in the aforementioned application by incorporation of a typical nickel catalyst, or the like, in the bottom of each of the regenerators to permit catalytic cracking of light hydrocarbons therein for integral production of hydrogen-rich gas. The light hydrocarbons

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may range from natural gas to distillate petroleum oils, but should preferably be of low average molecular weight not exceeding that of butane. Cracking of such light hydrocarbons in the presence of a catalyst and steam produces a gas containing at least 50% hydrogen and usually over 70% hydrogen. By producing the hydrogen-rich gas integrally the need for supplying hydrogen from an external source is completely eliminated.

Thermal cracking of the make oil is initiated in the upstream generator in the presence of said hydrogen-rich gas and completed as the reactants flow through the downstream generator. The process of thermally cracking a normally liquid hydrocarbon fuel to a fuel gas in the presence of a hydrogen-rich carrier gas in the absence of any catalytic materials is designated as hydrogasification. The temperatures prevailing within the generators during the hydrogasification part of the cycle range from 1200° to 2000° F., and preferably between 1300° and 1800° F.

By varying the reaction temperature and the ratio of the reactants, it is possible to produce fuel gases having a heating value ranging from 500 to 1000 B.t.u./s.c.f. which can be mixed with, or substituted for, all types of utility gases now in general use such as coke oven gas, carbureted water gas, oil gases and mixtures of these manufactured gases with natural gas, refinery gases or liquefied petroleum gases.

It should be noted that by thermal cracking of make oil in accordance with this method the cracking products are removed from the apparatus through the bottom of the downstream generator without passing through the regenerators. Thus, the regenerators are always kept relatively clean for the flow of steam, air and light hydrocarbons therethrough. This promotes good heat transfer so that reactants passing through the regenerators may be heated to the desired temperature in a minimum length of time. Any carbon which is produced during hydrogasification is laid down in the generators and is later completely burned during the blast cycle to supply a portion of the heat for the next hydrogasification step. Further, make oil or its cracking products which normally contain sulfur and various mineral constituents do not contact the catalyst beds in the bottoms of the two regenerators at any time during the operating cycle thereby preventing any possible fouling of the catalyst. The hydrogen-rich gas is produced by catalytic steam cracking distillate or gaseous hydrocarbon materials which do not tend to foul the catalyst to a significant extent, thereby permitting high rates of throughput and long catalyst life.

Thus, in summary, this invention distinguishes from the prior art, including that described in said copending applications, by the fact that it does not use any external source of hydrogen and does not permit contacting of make oil or cracking products with a catalyst in the production of fuel gases of heating values up to 1000 B.t.u./s.c.f.

Referring now to the drawing, which is a diagrammatic representation of apparatus suitable for use in practicing the process of this invention, the oil gas set comprises a pair of generators 11 and 12 which are interconnected by a crossover 14 at the upper ends thereof. A regenerator 21 connects to the lower end of generator 11 and a second regenerator 22 connects to the lower end of generator 12. These connections are through conduits 18 and 20, respectively. Tar pots 24 and 26 communicate with the conduits 18 and 20. Fresh quench water may be introduced into the tar pots through the lines 43 and 45, and recycled quenching medium through similar lines terminating in the tar pot inlets. The quenching medium may consist of the liquid hydrogasification products such as tar containing various proportions of water in the form of a dispersion.

Refractory shapes 16 and 17, disposed in the bottom of the regenerators 21 and 22, contain a cracking catalyst. The preferred catalyst consists of refractory shapes impregnated with 1% to 10% nickel in the form of nickel oxide. One-half inch to one inch diameter spheres composed of alumina, magnesia or zirconia have been found to be satisfactory. However, it has been found that alumina tends to react with nickel oxide at the temperatures employed to form a less active catalyst. Co-impregnation of alumina with nickel oxide and magnesium oxide has been found to be helpful in maintaining catalyst activity. Other suitable catalysts include other metals from the eighth group of the periodic system, such as cobalt and platinum. The catalysts are known in the art. Regenerators 21 and 22 are filled above the space occupied by the catalyst beds 16 and 17 with refractory shapes 25 which are capable of absorbing and releasing quantities of heat in exchange with fluids passing therethrough.

Stacks 55 and 57 connect to the upper ends of the generators 21 and 22, respectively. Suitable sources of steam, air and light hydrocarbons connect to the stacks 55 and 57 for introduction of these materials into the set through the regenerators. The light hydrocarbon which is converted into a hydrogen-rich gas is introduced into the regenerators through lines 70 and 71. To introduce blast air into the set a blower 46 is provided which connects to a conduit 48 having branch lines 50 and 52 connecting to stacks 55 and 57, respectively. It will be noted that the stacks 55 and 57 contain valves which may be used to close the stacks so that steam, light hydrocarbons and air introduced into the bottom thereof will flow downwardly through the set rather than out the stack. These valves are open only when flue gases or purge steam are discharged from the regenerators. Make oil and heat oil may be introduced through lines connecting to the top of generators 11 and 12. Additional heat oil may be introduced into the bottom of regenerators 21 and 22 to maintain the catalyst bed at the optimum temperature for cracking low molecular weight hydrocarbons with steam to hydrogen-rich gas. Heat oil may also be introduced into the bottom of each of the generators. These lines have nozzles on the ends thereof projecting into the generators and regenerators so that the oil can be introduced in the form of a spray. It is desirable to introduce additional blast air at or near each point of heat oil introduction. The exact method of heating the generators 11 and 12 and the catalyst beds 16 and 17 will be described below. However, it is important to note that the bottom heat oil burner in a generator is used only when the blast air flows upwardly through said generator and that the top heat oil burner in a generator is used only when the blast air flows downwardly through said generator. Similarly, the bottom heat oil burner in a regenerator is used only when blast air flows upwardly through the catalyst bed.

Outlets for product gases from tar pots 24 and 26 constitute the conduits 30 and 32. Downstream of these conduits is a pressure regulator 34 which causes pressure generated by production of gases within the set to build up to the predetermined maximum pressure for which the valve is set. The present process is preferably carried out at pressures below 20 pounds per square inch gauge for maximum gas yields. Higher pressures, say up to 50 pounds per square inch, will provide higher proportions of methane and ethane in the product gas but the total gas yield will be slightly reduced. A by-pass line 36 around the regulator 34 is provided for reduction of the set pressure to atmospheric pressure following the make portion of the cycle to permit the heating portion of the cycle to proceed at atmospheric pressure.

Preheaters for the make and feed oils may be provided but are not shown in the drawing. In operating this set, generator 11, generator 12 and regenerator 22 are first heated by combustion of heat oil. Air is introduced from the line 50 downwardly through regenerator 21 where it

will be preheated by passage over the hot refractory shapes 25. The preheated air then passes through catalyst bed 16, partially oxidizing the active metals and burning off any deposited carbon or combined sulfur. These oxidation and combustion reactions release heat which is stored in the refractory catalyst support. The hot blast gases then pass through the conduit 18 and upwardly through the generator 11 where carbon deposited from the previous make oil introduction period is burned off. Heat oil is introduced at the top of generator 12 and is burned with excess air passing downwardly through generator 12 and upwardly through the regenerator 22, heating the catalyst bed 17 and the refractory shapes 25 disposed therein. Additional heat oil and combustion air may be introduced into the bottom of regenerator 22 to maintain catalyst bed 17 at a temperature between 1000° and 2000° F. and preferably above 1300° F. Additional air may also be introduced into the top of generator 12. The set is then purged with steam introduced into regenerator 21 and exhausted through regenerator 22 and the stack 57 connected thereto.

Following the blast and purge cycles the make cycle is initiated when steam is passed into the regenerator 22 to superheat it to a temperature of over 1200°. Light hydrocarbon, such as natural gas, propane or butane, is introduced through line 71 simultaneously with the steam and is heated to the same temperature. Simultaneously, cushion steam is introduced into the top of regenerator 21 to prevent cracking products from entering regenerator 21 and contacting of idle catalyst bed 16. Upon passing over the catalyst bed 17 in the presence of steam the light hydrocarbon is converted into a hydrogen-rich gas. One volume of natural gas with one to two volumes of steam produce three to four volumes of hydrogen-rich gas. To produce hydrogen-rich gas at a rate of about 1000 cubic feet per hour, it is necessary to provide from ⅓ to ⅔ cubic foot of a typical commercial cyclic steam reforming catalyst. A typical range of analyses for hydrogen-rich gas is as follows:

	Percent
H ₂ -----	60-75
CO -----	10-25
CO ₂ -----	1-15
CH ₄ -----	0-10

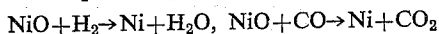
If the light hydrocarbon is a nitrogen-containing natural gas, the hydrogen-rich gas will also contain the equivalent amount of nitrogen. The hydrogen-rich gas and excess steam flow upwardly through the generator 12 and meet a spray of make oil which is introduced at the top of the generator. A portion of the make oil may be introduced into the generator 11 concurrent with flow therethrough. It may also be convenient to introduce additional process steam to the generators for purposes of make oil atomization. The hydrogen-rich gas, steam and make oil become thoroughly intermixed and hydrogasification is initiated in the upper portion of the generators 11 and 12. Hydrogasification is completed in the downstream generator 11 to provide a fuel gas ranging in heating value from 500 to 1000 B.t.u./s.c.f. The make gas is removed from the set through conduit 18 and tar pot 24. As soon as the gas enters the tar pot 24 it is quenched by means of the quench medium sprayed from line 37. The quench medium may be any of the following: the water-rich phase, the tar-rich phase or an emulsion of tar and water from the material condensed in the tar pots, any of which are cooled by recirculation through an appropriate heat exchanger. Also, auxiliary quenching may be provided by fresh quench water from line 43, if desired. The temperature of the gas is reduced to less than 800° and preferably below 400° F. by quenching and then flows through the conduit 30 into the discharge line 32. Liquid cracking products, and water if the temperature is sufficiently low, fall to the bottom of the pot. The chemical composition of the make gas is deter-

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mined by the quantity and composition of the hydrogen-rich carrier gas and the temperature, pressure and residence time in the generators. In turn, the quantity and composition of the hydrogen-rich gas is determined by the light hydrocarbon feed rate, the catalyst activity, the steam to light hydrocarbon ratio and the catalyst bed temperature.

During the make period the regenerator 21 is filled with cushion steam as indicated to insure flow of make gas from the generator 11 into the tar pot.

After the set has been purged of combustible materials with steam following the make period, it is necessary to reheat the generators 11 and 12 and to heat the regenerator 21 so that they are capable of imparting heat to the reactants entering into the second, reverse flow make period. This is done by introducing blast air from the conduit 52 into the regenerator 22. The air first partially oxidizes catalyst bed 17 and burns off any carbon deposits or combined sulfur. This catalyst bed has been reduced in the preceding make period by reactions such as



and $\text{NiO} + \text{CH}_4 \rightarrow \text{Ni} + \text{CO} + 2\text{H}_2$. Heat released by oxidation reactions such as



is stored in the refractory catalyst support. Deactivation of the catalyst and melting or fluxing of refractory materials due to excessive heat release from the highly exothermic catalyst oxidation reactions noted in the prior art are minimized as a result of the relatively low upstream catalyst bed temperature level after the make period, and the nature of the temperature gradient through the catalyst bed; i.e. the initial contacting of air and reduced catalyst occurs at the top of the bed where the temperatures are normally lowest, instead of the bottom of the bed where temperatures are normally highest. The air then flows upwardly through generator 12 to burn off carbon deposited within the generator during the previous cracking step. Heat oil is sprayed into the top of the generator 11 and burned with the air, and the hot products of combustion pass downwardly through the generator 11 and then are discharged through the regenerator 22 where they heat catalyst bed 16 and the refractory shapes 25. Heat oil and additional air may be introduced into the bottom of regenerator 21 to supplement the heat released from the combustion of heat oil in the generator 11 and from the combustion of deposited carbon. Additional air may also be introduced into the top of generator 11, as discussed in the description of the previous blast period. The extent of additional high-heat-release oxidation reactions in catalyst bed 16, already in a partially oxidized state from the preceding air blast period in the reverse direction, may be controlled by the amount of excess air permitted to pass through it, as described in detail in the prior art. However, the two-step oxidation procedure is an improvement over the methods of cyclic catalyst burn-off disclosed in the prior art because it permits much closer control over catalyst bed temperature and prevents excessive heat release rates. In the cycle described here, initial oxidation is carried out at relatively low temperature with a large amount of excess air passing downwardly through the catalyst bed which has been employed in the preceding make period. This catalyst bed is idle during the reverse make period and then is again subjected to oxidizing conditions at relatively high temperature by upward passage of blast gases of controlled free oxygen content before the next make period. Such an improved burn-off procedure is only feasible when two catalyst beds are disposed in the geometrical relationship employed in our process.

It will be understood that instead of heat oil, other fluid fuels such as hydrocarbon gases, liquefied petroleum gases or liquid by-products, may be used as a source of heat in this process.

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After reheating, the set is ready for making gas in the reverse direction. Steam and light hydrocarbon in the proper proportions are introduced through the regenerator 21, whereupon they attain a temperature of above 1200° F. As the materials pass over the catalyst bed 16 the light hydrocarbon is catalytically cracked in the presence of steam to produce a hydrogen-rich gas. This is accompanied by reduction of the oxidized portion of the catalyst. The hydrogen-rich gas and excess steam flow through the conduit 18 upwardly through the generator 11. Make oil is introduced into the top of the generator 11 countercurrent to the flow of the hydrogen-rich gas and steam. Hydrogasification is initiated in the generator 11 and is continued as the reactants pass through the crossover 14 and into the generator 12 where the thermal cracking of the make oil is completed. The make gas is discharged from the bottom of the generator 12 into the conduit 20 and downwardly into the tar pot 26. Simultaneously, cushion steam is introduced into the top of regenerator 22 from conduit 56 to keep the regenerator 22 free from cracking products. Cooled recycle quench medium is sprayed into the tar pot as the make gas enters to reduce the temperature of the make gas to below 800° F. The cooled make gas is then discharged from the tar pot into the line 32.

The remainder of the process is identical to that disclosed for the forward operation of the cycle except that it occurs in the reverse direction. Steam is introduced to purge the set, the set is reheated during the blast cycle and then the third make cycle is begun with cracking taking place initially in generator 12 and being completed in generator 11.

The flow of reactants in the make period can also be in the same direction as that of air and hot combustion product flow of the preceding blast period. In this case the reduced catalyst is first burned off with hot blast gases of controlled oxygen content flowing upwardly through the bed. The hot, partially oxidized catalyst bed is then idle in the reverse make period with cushion steam preventing entry of hydrogasification products. Blast air then passes downwardly through the hot bed with any heat release from additional oxidation reactions being stored in the refractory support. At the same time, the reduced, relatively cool downstream catalyst bed is being reheated, burned off and partially oxidized. This operating cycle, while feasible, affords less control over catalyst bed temperature than the preferred cycle in which the make period is in the reverse direction of the preceding blast period. However, it is apparent that by introduction of heat oil into the bottoms of the regenerators 21 and 22, and the bottoms and/or the tops of generators 11 and 12, it is possible to control the temperatures prevailing within the generators 11 and 12 and in the catalyst beds 16 and 17 in the bottom of the regenerators 21 and 22. The flexibility of the process permits converting a variety of petroleum and liquid fossil fuel feedstocks into gaseous products of critical composition determined by the properties of the send-out gas which it may be desired to supplement or substitute for.

Under normal operating conditions with residual make oils a make gas of approximately 1000 B.t.u./s.c.f. heating value will be produced when introducing 15 to 25 s.c.f. of process natural gas per gallon of make oil, and 1 to 2 pounds of steam per gallon of make oil, into the top of the upstream regenerator at natural gas feed rates in the order of 500 s.f.c./c.f. catalyst-hour and average catalyst bed and generator temperatures of 1500° to 1600° F. The catalyst would have to contain more than 2 weight percent of available nickel on a suitable porous refractory support such as alumina or magnesia to give the required conversion activity. Available nickel is characterized by ready solubility in strong mineral acids. The make gas heating value may be lowered by increasing the amount of process natural gas in relation to the amount of make oil. Steam and catalyst require-

ments will be proportional to the amount of natural gas used.

In the example below, operating results for this process are presented when producing high B.t.u. gas from reduced crude oil using natural gas as the light hydrocarbon for the production of hydrogen-rich carrier gas. The catalyst beds in the regenerators consist of one inch diameter alumina spheres impregnated with 5 weight percent nickel and one weight percent magnesium oxide.

Process feeds:	
Make oil, gal./hr. -----	51.31
Process natural gas, s.c.f./hr. -----	971
Heat oil -----	
To generators, gal./hr. -----	8.0
To regenerators, gal./hr. -----	5.0
Blast air -----	
To upstream regenerator, s.c.f./hr. -----	33,200
To downstream regenerator, s.c.f./hr. -----	6400
Steam feed, lb./hr. -----	
Process steam:	
To generators -----	128
To regenerators -----	72
Purge steam -----	201
Cushion steam -----	144
Operating conditions:	
Temperatures, ° F. -----	
Average generator -----	1551
No. 1 generator:	
Top -----	1631
Middle -----	1574
Bottom -----	1570
No. 2 generator:	
Top -----	1638
Middle -----	1515
Bottom -----	1480
No. 1 regenerator:	
Top -----	200
Middle -----	666
Catalyst zone -----	
Top -----	1445
Middle -----	1738
Bottom -----	1918
No. 2 regenerator:	
Top -----	241
Middle -----	803
Catalyst zone -----	
Top -----	1466
Middle -----	1714
Bottom -----	1924
Quench liquid -----	158
First stage condenser inlet -----	200
Maximum make pressure, p.s.i.g. -----	9.0
Catalyst volume per regenerator, c.f. -----	6.0
Process natural gas space velocity, s.c.f./c.f. catalyst-hr. -----	421
Process steam/natural gas ratio, lb./M c.f. -----	74.3
Operating results:	
Product distribution, wt. percent -----	
Gas -----	60.63
Liquid products ¹ -----	34.30
Coke ² -----	5.07
Make gas -----	
S.c.f./hr. -----	6337
S.c.f./gal. -----	123.5
Feed consumption -----	
Make oil, gal./million B.t.u. of make gas -----	8.13
Heat oil, gal./million B.t.u. of make gas -----	1.27
Natural gas, M c.f./million B.t.u. of make gas -----	0.154
Natural gas properties:	
Composition, mole percent -----	
Methane -----	88.0
Ethane -----	4.8
Propane -----	1.8
Butanes -----	0.44
Pentanes -----	0.07
Hexanes -----	0.06
Heptanes -----	0.02
Carbon dioxide -----	0.76
Nitrogen -----	3.9
Helium -----	0.15
Total -----	100.00
Heating value, B.t.u./s.c.f. -----	1027
Specific gravity, air=1 -----	0.607
Hydrogen-rich gas properties:	
Composition, mole percent -----	
Hydrogen -----	71.6
Carbon dioxide -----	5.5
Carbon monoxide -----	15.7
Methane -----	5.9
Nitrogen -----	1.3
Total -----	100.0
Heating value, B.t.u./s.c.f. -----	337
Specific gravity, air=1 -----	0.332
Make gas properties:	
Composition, mole percent -----	
Hydrogen -----	28.7
Methane -----	22.5
Ethane -----	3.0
Propane -----	0.2
Ethylene -----	17.2
Propylene -----	6.3

Butene and higher -----	1.1
Diolefins and acetylene -----	2.2
Benzene -----	1.5
Toluene -----	0.3
Carbon dioxide -----	3.6
Carbon monoxide -----	11.3
Nitrogen -----	2.1

Total ----- 100.0

Heating value, B.t.u./s.c.f. ----- 996.2

Specific gravity, air=1 ----- 0.737

¹ By difference.
² Calculated from difference in carbon content of flue gas (CO + CO₂) and carbon content of heat oil assuming 6 weight percent hydrogen content of deposited coke.

The sequence of valve operation which corresponds to the above example is as follows:

Valve function:	Time, seconds
No. 1 process steam open -----	0
No. 2 cushion steam open -----	0
Bypass open -----	0
No. 1 natural gas open -----	0
No. 1 make oil open -----	5
No. 1 natural gas close -----	90
No. 1 make oil close -----	95
No. 1 process steam close -----	95
No. 1 purge steam open -----	105
No. 2 purge steam open -----	105
No. 2 cushion steam close -----	106
Bypass close -----	115
No. 1 purge steam close -----	115
No. 2 purge steam close -----	115
No. 2 stack open -----	116
No. 1 air blast open -----	120
No. 2 generator heat oil open -----	123
No. 2 regenerator heat oil open -----	123
No. 2 generator heat oil close -----	220
No. 2 regenerator heat oil close -----	220
No. 1 air blast close -----	221
No. 1 purge steam open -----	222
No. 2 stack close -----	242
No. 1 purge steam close -----	242
No. 2 process steam open -----	242
No. 1 cushion steam open -----	242
Bypass open -----	242
No. 2 natural gas open -----	242
No. 2 make oil open -----	247
No. 2 natural gas close -----	332
No. 2 make oil close -----	337
No. 2 process steam close -----	337
No. 2 purge steam open -----	342
No. 1 purge steam open -----	347
No. 1 cushion steam close -----	348
Bypass close -----	357
No. 2 purge steam close -----	357
No. 1 purge steam close -----	357
No. 1 stack open -----	358
No. 2 air blast open -----	362
No. 1 generator heat oil open -----	365
No. 1 regenerator heat oil open -----	365
No. 1 generator heat oil close -----	462
No. 1 regenerator heat oil close -----	462
No. 2 air blast close -----	463
No. 2 purge steam open -----	464
No. 1 stack close -----	484
No. 2 purge steam close -----	484

Other modifications of the invention will be evident to those skilled in the art without departing from the scope and spirit of the invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A cyclic regenerative process for producing an oil gas in a gas generating set including a first and a second generator communicating with a first and a second regenerator, respectively, each of said regenerators containing a cracking catalyst, comprising heating the first regenerator and both generators, passing steam and a light hydrocarbon into said first regenerator to heat said

steam and light hydrocarbon to above 1200° F. and then crack said light hydrocarbon in the presence of said steam and the catalyst in said first regenerator to produce a hydrogen-rich gas containing over 50% hydrogen, causing said hydrogen-rich gas to flow in a stream through said first generator, introducing make oil into said stream to initiate thermal cracking of said oil, passing the partially cracked products into said second generator to complete cracking of said oil at a temperature of 1300° to 1800° F. to a fuel gas, and discharging said fuel gas from the set directly from the downstream end of said second generator.

2. The process of claim 1 wherein said light hydrocarbon has a molecular weight ranging from that of methane to that of kerosene and said make oil has a molecular weight up to and including that of Bunker "C" oil.

3. The process of claim 1 wherein the steps are repeated with the flow of reactants in the reverse direction through the set.

4. The process of claim 1 wherein pressure within the set is maintained at from atmospheric to 20 pounds per square inch gauge during the period of light hydrocarbon and make oil introduction.

5. A cyclic regenerative process for producing an oil gas in a gas generating set including a first and a second generator communicating with a first and a second regenerator, respectively, each of said regenerators containing a cracking catalyst, comprising flowing air through the second regenerator and both generators while introducing fluid fuel into said generators, passing the products of combustion through said first regenerator, thereby heating said first regenerator and both generators, purging the set with steam and maintaining a cushion of steam in said second regenerator, passing steam and a light hydrocarbon into said first regenerator to heat said steam and light hydrocarbon to above 1200° F. and then crack said light hydrocarbon in the presence of said steam and the catalyst in said first regenerator to produce a hydrogen-rich gas containing over 50% hydrogen, causing said hydrogen-rich gas and excess steam to flow in a stream through said first generator, introducing make oil into said stream to initiate thermal cracking of said oil, passing the partially cracked products and excess steam into said second generator to complete cracking of said oil at a temperature of 1300° to 1800° F. to a high B.t.u. oil gas, discharging said oil gas from the set directly from the downstream end of said second generator, and immediately quenching said oil gas to cool it.

6. The process of claim 5 which comprises additionally introducing fluid fuel and air into said first regenerator upstream of the cracking catalyst while fluid fuel is being introduced into said generators, and introducing make oil into said second generator while the make oil is being introduced into said stream flowing through said first generator.

7. The process of claim 5 wherein said light hydrocarbon is natural gas and said make oil has a molecular weight up to and including that of Bunker "C" oil.

8. The process of claim 5 wherein the steps are repeated with the flow of reactants in the reverse direction through the set.

9. A method for producing a fuel gas comprising passing a light hydrocarbon having an average molecular weight not exceeding that of butane in admixture with steam over a catalyst bed disposed within a cracking vessel, said bed and mixture of steam and hydrocarbon being maintained at a temperature of between 1200° and 2000° F. to form a hydrogen-rich carrier gas containing at least 50% hydrogen, simultaneously introducing a make oil having a molecular weight not in excess of Bunker "C" oil into said vessel downstream of said catalyst bed, causing said make oil and said carrier gas to become intimately mixed, maintaining said mixture at a temperature of 1300° to 1800° F. and at a pressure not exceeding 20 pounds per square inch gauge to thermally crack said make oil, thereby producing a fuel gas having a heating value of from 500 to 1000 B.t.u.'s per standard cubic foot.

10. The method of claim 9 wherein said light hydrocarbon is natural gas and is supplied at a rate of 15 to 25 standard cubic feet per gallon of make oil, said steam is supplied at a rate of 1 to 2 pounds per gallon of make oil, and said fuel gas has a heating value of approximately 1000 B.t.u.'s per standard cubic foot.

References Cited in the file of this patent

UNITED STATES PATENTS

2,605,176	Pearson	July 29, 1952
2,720,450	Haug	Oct. 11, 1955
2,759,806	Pettyjohn et al.	Aug. 21, 1956
2,807,528	Pettyjohn et al.	Sept. 24, 1957

FOREIGN PATENTS

693,724	Great Britain	July 8, 1953
755,634	Great Britain	Aug. 22, 1956