Jan. 3, 1961 C. J. COBERLY 2,967,205

PROCESS OF AND APPARATUS FOR PRODUCING ACETYLENE AND ETHYLENE

Filed Sept. 24, 1956 3 Sheets-Sheet 1

Fig. 1.

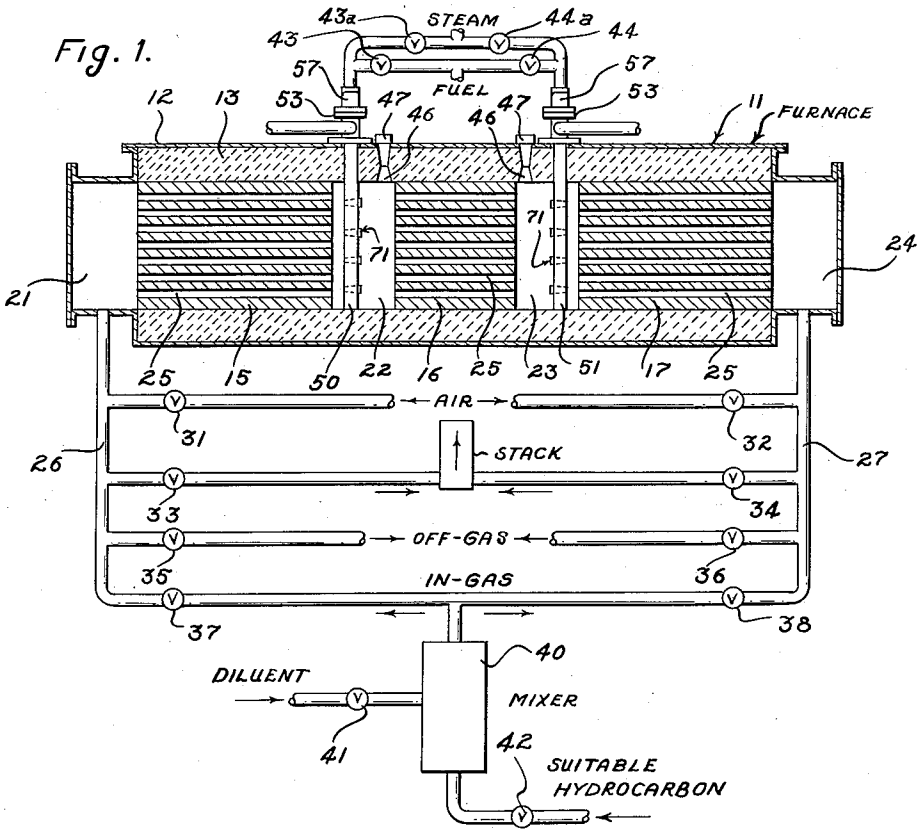


Fig. 2.

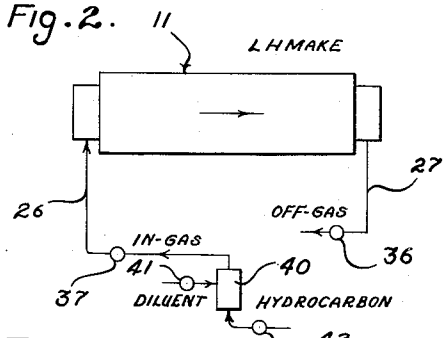


Fig. 5.

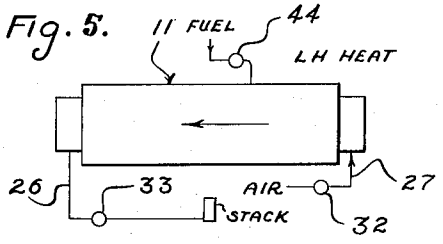


Fig. 3.

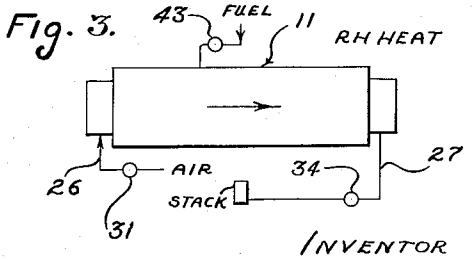
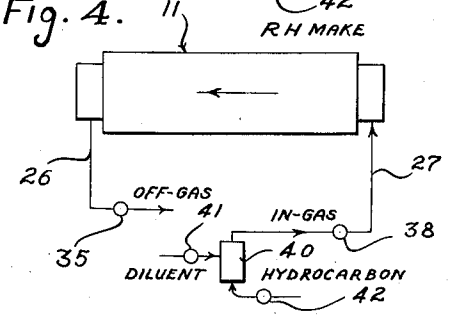


Fig. 4.



INVENTOR

CLARENCE J. COBERLY

BY HIS ATTORNEYS

HARRIS, KIECH, FOSTER & HARRIS

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Fig. 6.

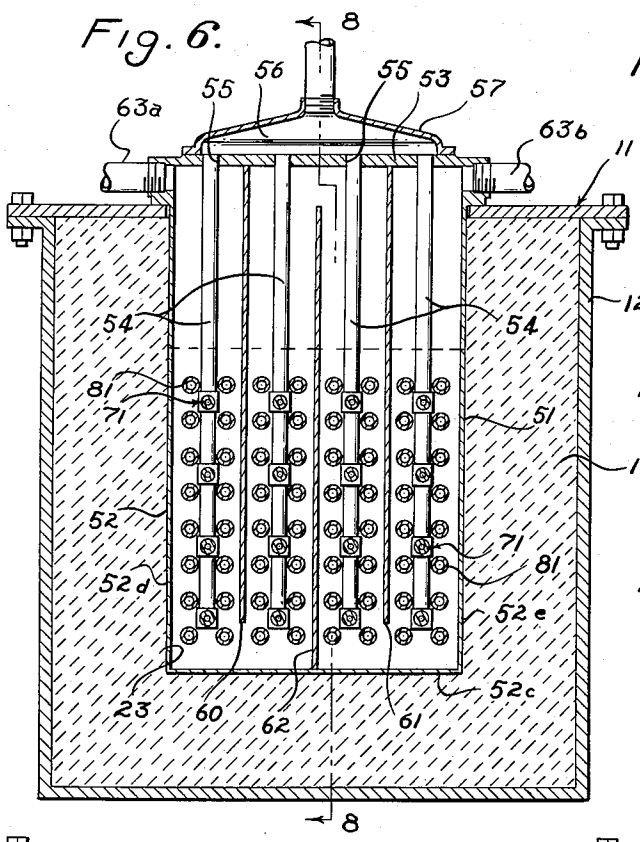


Fig. 8.

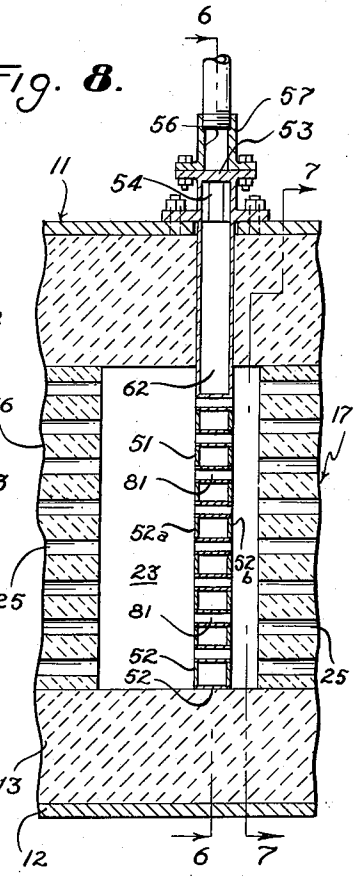
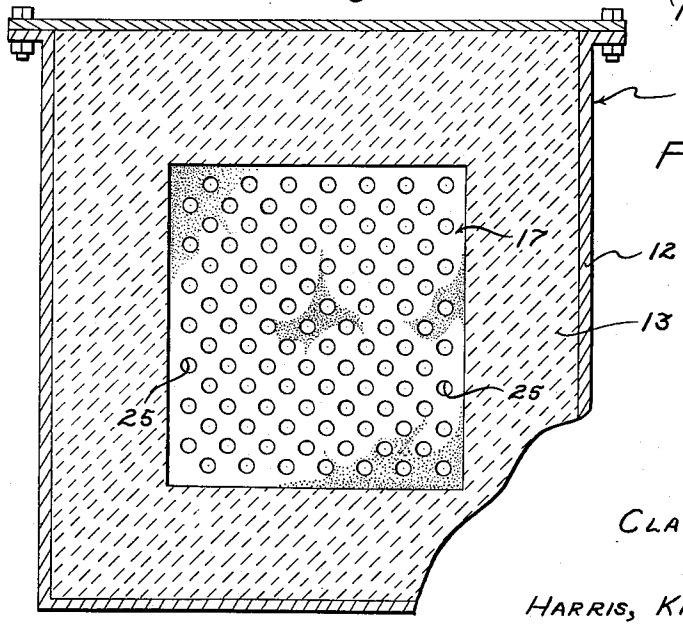


Fig. 7.



INVENTOR

CLARENCE J. COBERLY

BY HIS ATTORNEYS

HARRIS, KIECH, FOSTER & HARRIS

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Fig. 9.

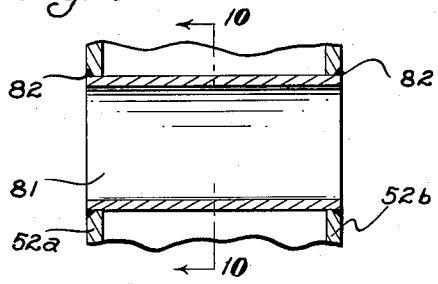


Fig. 10.

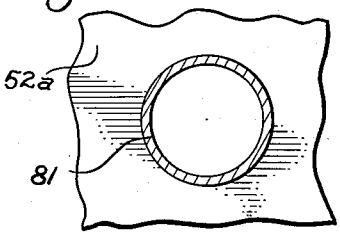


Fig. 11.

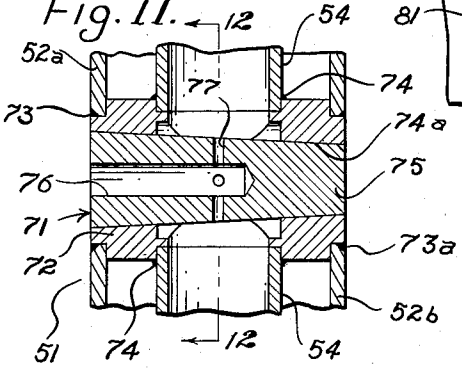


Fig. 12.

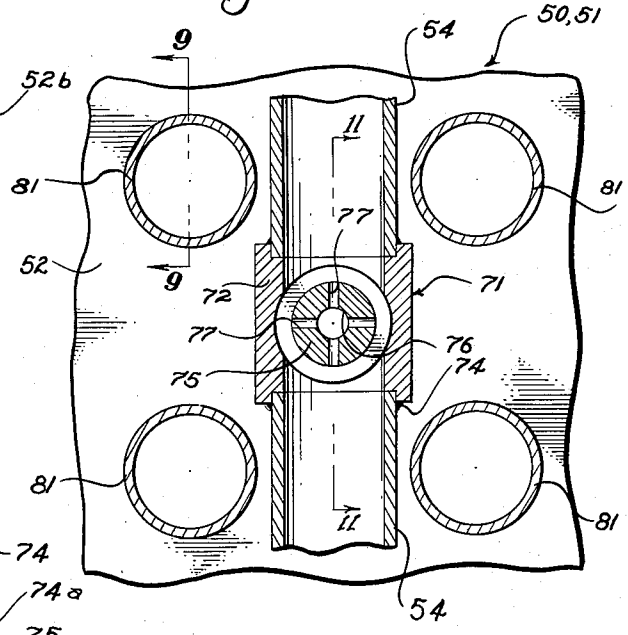


Fig. 13.

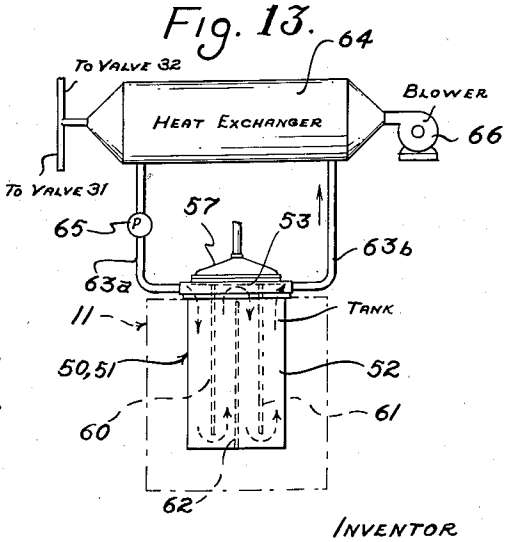
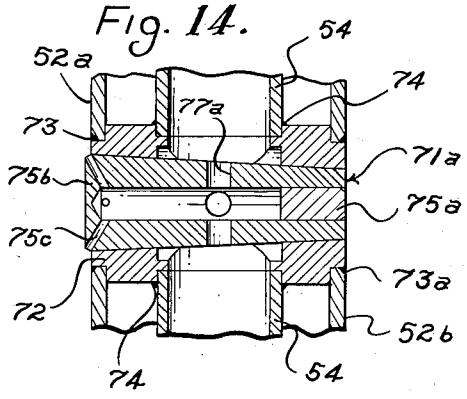


Fig. 14.



INVENTOR

CLARENCE J. COBERLY

BY HIS ATTORNEYS

HARRIS, KIECH, FOSTER & HARRIS

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2,967,205

PROCESS OF AND APPARATUS FOR PRODUCING ACETYLENE AND ETHYLENE

Clarence J. Coberly, San Marino, Calif., assignor to Wulff Process Company, Huntington Park, Calif., a corporation of California

Filed Sept. 24, 1956, Ser. No. 611,541

13 Claims. (Cl. 260—679)

The invention relates to the production of an off-gas or cracked gas containing a desired hydrocarbon such as, for example, acetylene, or ethylene, and other olefins, from an in-gas containing a suitable hydrocarbon, such as, for example, propane, by the pyrolysis of the in-gas in a suitable regenerative furnace.

The nature and substance of the invention may be briefly summarized as comprising a new and useful method of, and apparatus for, operating a novel and useful furnace which may be used to pyrolyze hydrocarbons.

A primary object of the invention is to provide such a furnace having heating means adapted to permit the size of the furnace, and consequently its capacity, to be varied through a wide range without substantial variation in yield of the desired hydrocarbon.

A further object is to provide such a furnace having quenching means adapted to efficiently and rapidly quench the cracked gases formed by pyrolysis in the furnace to temperatures at which the desired hydrocarbon is stable. Another related object is to maintain the temperature of the quenching means above the dew point of tarlike materials in the cracked gas, to prevent the deposit of such tarlike materials.

Still another object of the invention is to provide such a furnace with fuel injection means adapted to efficiently supply fuel thereto to promote uniform combustion therein. A related object is to operate such a furnace so that the fuel injection means is maintained at a temperature below the temperature at which the fuel would be cracked to form undesirable tarlike materials.

Other objects, features, and advantages will appear from the following specification and the drawings, which are for the purpose of illustration only, and in which:

Fig. 1 is a diagram, partly in vertical section, showing the furnace of my invention and the piping and auxiliary apparatus adapted to produce a desired hydrocarbon from a suitable hydrocarbon.

Figs. 2, 3, 4, and 5, are diagrams illustrating the four steps of a cyclic process used to practice my invention.

Fig. 6 is a transverse vertical section through the furnace on a plane indicated by the line 6—6 in Fig. 8.

Fig. 7 is a transverse vertical section through the furnace on a plane indicated by the line 7—7 in Fig. 8.

Fig. 8 is a longitudinal vertical section of a portion of the furnace on a plane indicated by a line 8—8 in Fig. 6.

Fig. 9 is a longitudinal section through a portion of a quencher and quencher tube of the invention on a plane indicated by a line 9—9 in Fig. 12.

Fig. 10 is a cross section on a plane indicated by a line 10—10 in Fig. 9.

Fig. 11 is a longitudinal section through a portion of a quencher and fuel nozzle on a plane indicated by a line 11—11 in Fig. 12.

Fig. 12 is a cross section through a portion of a quencher and fuel nozzle on a plane indicated by a line 12—12 in Fig. 11.

Fig. 13 is a diagram illustrating the cooling system of the invention.

Fig. 14 is a view similar to Fig. 11 of an alternative form of fuel nozzle.

A furnace 11 adapted for use in my invention is diagrammatically illustrated in Fig. 1. It consists of a steel shell 12 having a heat insulating lining 13. Carried inside the lining 13 are three spaced regenerative masses 15, 16, and 17 providing four spaces, a left-hand end space 21, a left central space 22, a right central space 23, and a right-hand end space 24, as viewed in Fig. 1. Each of the regenerative masses has a plurality of longitudinal channels 25 which extend longitudinally through the mass, the channels 25 connecting the spaces 21 to 24 in a chain of openings through which gas may pass from the left end space 21 to the right end space 24, or vice versa. A pipe 26 delivers gas to, or takes it from, the left-hand end space 21 and a pipe 27 delivers gas to, or takes it from, the right-hand end space 24.

Air under pressure may be delivered to the pipe 26 through a valve 31 and to the pipe 27 through a valve 32. Waste products of combustion may be delivered to a stack from the pipe 26 through a valve 33 and from the pipe 27 through a valve 34. Off-gas or cracked gas may be taken from the pipe 26 through a valve 35 and from the pipe 27 through a valve 36. In-gas may be delivered to the pipe 26 through a valve 37 and to the pipe 27 through a valve 38. In-gas may be a mixture formed in a mixer 40 of a diluent such as steam, delivered through a valve 41, and a suitable hydrocarbon delivered through a valve 42. Fuel gas may be delivered to the space 22 through a valve 43 and to the space 23 through a valve 44. Also, steam may be delivered to the space 22 through a valve 43*a* and to the space 23 through a valve 44*a*.

Various processes may be carried on by the mechanism shown in Fig. 1 and above described. For example, an off-gas containing acetylene or ethylene, or both, may be produced from an in-gas containing propane, in a four-step process which will now be described. Before this process can be started, the masses 15, 16, and 17 must be preheated. Such preheating can be conveniently performed in two steps. Each of the spaces 22 and 23 has a torch opening 46 which is normally closed by a plug 47. All of the valves 31 to 38, 41 to 44, 43*a* and 44*a* being closed, the valve 34 is opened, thus connecting the space 24 with the stack. The left-hand plug 47 is then removed from its opening communicating with the space 22 and hot gas or flame from a torch is fed into the space 22 through the opening 46 and the hot gas therefrom passes through the channels 25 in masses 16 and 17 and this hot gas tends to heat masses 16 and 17 before passing through the pipe 27 and valve 34 to the stack. The torch is then withdrawn from the hole 46 in the space 22 and the plug 47 is replaced and the valve 34 is closed. The valve 33 is then opened, the right-hand plug 47 is removed from its opening 46 into the space 23 and hot gas or flame is passed from a torch into the space 23 and the hot gas therefrom passes through the channels 25 in the masses 16 and 15 and through the pipe 26 and the valve 33 to the stack. This accomplishes the preheating step.

As as alternative method of performing the initial preheating step is, with all of the valves 31 to 38, 41 to 44, 43*a* and 44*a* being closed, the valve 33 is opened to the stack, the fuel valve 44 is partially opened to permit fuel to flow into the right central space 23, the air valve 32 is opened to permit air to pass to the right end space 24 and through the channels 25 in the right-hand mass 17 into the space 23 where it mixes with fuel, the mixture being ignited through the right-hand port 46 which is then closed. The hot products of such combustion then

pass from the space 23 through the mass 16, the space 22, and the mass 15 to the stack through the pipe 26 and the valve 33, which heats the masses 16 and 15. When the masses 16 and 15 have attained a desired temperature, the valves 32, 33, and 44 are closed and valves 31, 34 and 43 are opened to a required extent to permit air to pass through the valve 31, the left end space 21, and the mass 15 into the left central space 22 where it mixes with fuel admitted thereto through the valve 43. Such mixture in the space 22 is then ignited and the hot products of such combustion then pass through the mass 16, the right central space 23, the mass 17, and the valve 34 to the stack. This is continued until the mass 17 attains a desired starting temperature, which completes this alternative form of preheating step.

It will be noted that in the preheating step the mass 16 has been heated by both a left-to-right and a right-to-left flow of hot gas. The central mass 16 is, therefore, much hotter than either of the masses 15 or 17. Also, both of the masses 15 and 17 will be much hotter at their inner ends adjacent to the spaces 22 and 23 than at their outer ends adjacent to the end spaces 21 and 24.

Such preheating step should be performed prior to starting cyclic production of the desired hydrocarbon, such as acetylene, but the cycle now to be described maintains the masses in proper heat condition as long as the cycle persists, subject, however, to brief interruptions of the cyclic process at long intervals of time when it is desired to correct any undesired distribution of heat in the masses.

The four steps of the cyclic process which is chosen to illustrate one use of the invention claimed herein are illustrated by Figs. 2, 3, 4, and 5, and will now be described.

Preparatory to the cyclic process next to be described the furnace has been preheated as previously described. For the manufacture of acetylene the central mass 16 during the cyclic step may be at a temperature somewhat higher than 2200° F. and the masses 15 and 17 are at a temperature somewhat lower than 2200° F. adjacent to the central spaces 22 and 23 and at a much lower temperature at their outer ends adjacent to their respective end spaces 21 and 24. For the production of ethylene primarily, or a mixture of ethylene and acetylene, such temperatures may be somewhat lower to obtain optimum yields. Also, as will be understood, if in the preheating step the hot products of combustion are last passed from right-to-left, as seen in Fig. 1, the center mass 16 and the left-hand mass 15 will be at a higher temperature than the right-hand mass 17 and in the initial make step the in-gas should be passed from left-to-right. However, if in the preheating step the hot products of combustion are last passed from left-to-right the center mass 16 and the right-hand mass 17 will be at a higher temperature than the left-hand mass 15 and in this case in the initial make step the in-gas should be passed from right-to-left. It is immaterial which way the cyclic operation is started.

During the LH make step as shown in Fig. 2 an in-gas is formed by mixing a suitable hydrocarbon, such as propane, delivered to the mixer 40 through the valve 42, with a diluent, such as steam, admitted to the mixer 40 through the valve 41, the in-gas so produced being delivered through the valve 37 and the pipe 26 to the left-hand end space 21 of the furnace 11. The in-gas flows from left-to-right through the furnace 11 and is pyrolyzed in the furnace 11 to form an off-gas containing a desired hydrocarbon, the off-gas being delivered to other apparatus, not shown or described, through the valve 36 from the pipe 27. Such pyrolysis in the LH make step occurs principally in the center mass 16 but some also occurs in the left-hand mass 15. During the make step heat is withdrawn from the hot regenerative masses in the furnace to (*a*) provide heat to bring the in-gas up to a certain reactive temperature and (*b*) to provide the heat necessary to perform the pyrolysis.

The RH heat step shown in Fig. 3 may follow the LH make step. In the RH heat step, air is delivered through the valve 31 and the pipe 26 to the left-hand end of the furnace and passes from left-to-right through the furnace, being itself heated by and in turn cooling the mass 15. Fuel gas is delivered through the valve 43 to the space 22 where it is mixed with the hot air delivered to the space 22 from the channels 25 in the mass 15 and burned. The products of such combustion pass rightwardly through the furnace, passing to the stack through the mass 16, the central space 23, the right-hand mass 17, the right end space 24, the pipe 27, and the valve 34. This is continued until the center mass 16 and at least the inner end of the right-hand mass 17 are raised above a desired pyrolysis temperature. This is followed by the RH make step.

The RH make step is shown in Fig. 4. The in-gas produced in the mixer 40 is delivered through the valve 38 and pipe 27 to the right-hand end of the furnace and passes from right-to-left through the furnace 11, pyrolysis taking place principally in the center mass 16, and to a lesser degree in the right-hand mass 17. The off-gas leaves the furnace through the valve 35.

The LH heat step is shown in Fig. 5 and may follow the RH make process shown in Fig. 4. In the LH heat step air is delivered to the furnace 11 through the valve 32 and the pipe 27, and is mixed with fuel gas in the space 23 delivered to the space 23 through the valve 44 and burned. The products of combustion are delivered to the stack through pipe 26 and the valve 33.

Disposed in the central spaces 22 and 23 are transverse members 50 and 51, respectively, which are identical, except oppositely disposed, so only the member 51 will be described in detail. The member 51, as best shown in Figs. 6, 8, and 9 to 13, inclusive, includes a generally rectangular container member 52 which is preferably inset through the top of the furnace 11 into the right central space 23. The container member 52 has front and rear walls 52*a* and 52*b*, respectively, and a bottom wall 52*c*, as shown in Fig. 8, and side walls 52*d* and 52*e*, as shown in Fig. 6, and an integral head member 53 which is suitably secured in gas-tight relationsihp to the top of the shell 12. The container member 52 thus forms a closed box which completely covers transversely the cross-sectional area of the right central space 23. Depending from the head member 53 are four fuel pipes 54, the lower ends of which are closed and the upper ends of which are in open communication with a manifold space 56 provided by a cover bell 57 with which the fuel supply is connected through the valve 44 and its piping.

Also suspended from the head member 53 are two outer baffle plates 60 and 61, the lower ends of which stop short of the bottom wall 52*c*, and supported by and extending upwardly from the bottom wall is a central baffle plate 62, the upper end of which stops short of the head member 53. Connected to opposite sides of the head member 53 are coolant pipes 63*a* and 63*b* which, as shown diagrammatically in Fig. 13, are connected to a heat exchanger 64, there being a suitable pump 65 in the line of the pipe 63*a*. The pump 65 is adapted to circulate a suitable liquid from the heat exchanger through the pipe 63*a* into the container member 52 and therethrough around the baffle plates 60, 62, and 61, as indicated by the arrows in Fig. 13, and through the pipe 63*b* back through the heat exchanger. Air is preferably blown through the tubes (not shown) of the heat exchanger 64 by a blower 66 to the valves 31 and 32, or either, to be used in the heating steps of the method described herein.

Each of the depending fuel pipes 54 is provided with a plurality of fuel nozzle assemblies 71 (best shown in Figs. 11 and 12). Each of the fuel nozzle assemblies 71 has a body 72 of generally tubular form which is welded at 73 and 73*a* into suitable horizontally aligned

holes in the front and rear walls 52*a* and 52*b*, respectively. For convenience of manufacture, the depending fuel pipes 54 are made in short lengths and the appropriate ends are welded into suitable vertically aligned holes in the bodies 72, as indicated at 74. The body 72 is provided with a horizontally disposed conical opening 74*a* into which is driven a nozzle plug 75 which has a horizontal bore 76 partially therethrough and a plurality of circumferentially spaced radial bores 77 communicating with the interior of the fuel pipe 54 in which its fuel nozzle assembly is located. The bores 76 of the nozzle plugs 75 in the transverse member 51 open into the right central space 23 and are directed towards the central mass 16, and the similar bores in the transverse member 50 open into the left central space 22 and are directed towards the central mass 16, as indicated in Fig. 1.

As best shown in Fig. 6, the nozzle assemblies 71 are preferably spaced uniformly throughout the central space in which they are located, to provide a uniform fuel distribution in such space to insure a substantially uniform heating of the central mass 16 during both the LH and RH heating steps described hereinbefore, which is an important feature of the invention. With variations of the cross-sectional area of the central mass 16 the number of depending fuel pipes 54 and the number of nozzle assemblies 71 in each may be varied to readily provide a uniform fuel distribution for any desired cross-sectional area. Thus, if such area is increased, the number of fuel pipes 54 or nozzle assemblies 71, or both, may be increased, or, conversely, for smaller areas such number may be reduced. This method of fuel distribution is particularly desirable in regenerative furnaces having a large cross-sectional area, in which it is virtually impossible to provide a uniform fuel distribution across the entire area if the fuel is injected into the furnace by jets or nozzles in the sides of the furnace by conventional means.

Also connecting the front and rear walls 52*a* and 52*b* of the container 51 are a plurality of short flue tubes 81 which are arranged in a substantially uniform pattern between the fuel tubes 54 and the nozzle assemblies 71. As best shown in Fig. 9, each of the flue tubes 81 is welded at its ends to the front and rear walls 52*a* and 52*b*, as at 82. The total cross-sectional open area of the flue tubes 81 is preferably approximately equal to the total cross-sectional area of the channels 25 in the masses 15, 16, and 17 so that the velocity of passage of gas therethrough is substantially uniform, and this is a further object of the invention.

As will be noted, the coolant which is circulated through the container 51 passes around the flue tubes 81 and serves to cool gas passing therethrough as desired. Thus, during the RH make step the center mass 16 is at the relatively high temperature required for pyrolysis and the in-gas passes from the right end space 24 through the channels 25 in the right-hand mass 17 and then through the flue tubes 81 in the transverse member 51 and thence through the central mass 16 where the major part of the pyrolysis occurs, and into the left central space 22 from which the cracked gas flows through the flue tubes 81 of the transverse member 50 and thence through the left-hand mass 15 and out of the furnace. If at this time coolant is circulated through the transverse member 50 the cracked gas passing through the flue tubes 81 thereof is quickly cooled by such coolant to a temperature at which the desired hydrocarbon therein, such as acetylene, is stable, which provides a much more rapid quench of the cracked gas than would be possible in the left-hand mass 15 alone without the presence of the transverse member 50 as normally practiced by conventional furnaces. Such prompt and effective cooling of the cracked gas substantially increases the yield of the desired hydrocarbon, such as acetylene, therein. As will be understood, during the LH make step coolant circulated through the transverse member 51 serves to cool the cracked gas passing therethrough.

The coolant circulated through the transverse members 50 and 51 is necessarily a liquid having a relatively high boiling temperature, such as "Dow Therm," which can be operated at temperatures of 600° F. to 700° F. without boiling, or by a liquid metal such as mercury, sodium, or lead. Due to the high temperatures existing in the furnace 11 to obtain pyrolysis such a high temperature liquid will normally be circulated at temperatures in excess of 500° F. Thus, although such liquid is generally referred to herein as a "coolant" for the hot gas at much higher pyrolysis temperatures, still in the operation of my invention such coolant is actually quite hot. This provides a further advantage in the practice of this process as during each heating step this coolant is employed to preheat the air passing into the furnace. Thus, in the LH heat step, air passing from the pipe 27 through the right-hand mass 17 passes through the transverse member 51 through which such relatively hot coolant is being circulated.

Having described the function and operation of the apparatus qualitatively, the quantitive information will now be given so that anyone skilled in the art will be able to practice the invention and obtain the improved results to be derived therefrom.

In the furnace of the type described in which the ceramic masses 15, 16, and 17 each has a cross-sectional area of 2.5 square feet the heat duty thereof during each heating step will be 50,000 B.t.u. per minute in producing acetylene, or about 20,000 B.t.u. per minute per square foot of cross-section. Since this invention is applicable to furnaces having a wide variation in sizes, the proportions given hereinafter will be on the basis of such a furnace having ceramic masses of one square foot in cross-section.

The fuel supplied to the fuel nozzles 71 will normally be off-gas formed by the furnace during the make steps and after the acetylene or other desired product has been removed therefrom. Such off-gas normally has a heat value of about 500 B.t.u. per cubic foot. In producing acetylene from propane the composition of the off-gas will be approximately as follows:

CO	7.31
N_2	4.09
H_2	58.51
CH_4	21.84
C_2H_4	6.27
C_2H_6	.1
C_3H_4	.1
C_3H_8	.21
CO_2	1.57

The heat value of such an off-gas will be about 475 B.t.u. per cubic foot. Therefore, it will be necessary to burn 42 s.c.f.m. (standard cubic feet per minute) per square foot of cross-sectional area of the ceramic masses. To accomplish this, I prefer to arrange the fuel nozzles 71 on approximately 4½" centers, to provide 6.4 fuel nozzles per square foot of cross-section, and each fuel nozzle will be required to burn 6.6 s.c.f.m. of the off-gas. If natural gas is used for fuel, it will have a heat value of about 1000 B.t.u. per cubic foot, and therefore only 20 s.c.f.m. will be required, or about 3.1 s.c.f.m. per nozzle. As shown in Fig. 12, four orifices 77 are provided for each fuel nozzle 71, and sufficient pressure should be maintained in the fuel pipes 54 to provide an in-gas flow through the orifices at the critical velocity of the in-gas, which is about 2500 feet per second. Therefore, for the use of such an off-gas as fuel each orifice 77 should have a diameter of about 0.06 inch. If natural gas is used as fuel, the diameter of each orifice should be about 0.05 inch.

The diameter of the bores 76 is not critical, but I have found that good results are obtained if the fuel velocity in

such bores is about the same as the air velocity through the flue tubes **81**. Since there are four flue tubes **81** for each fuel nozzle **71** and the ratio of air to off-gas for complete combustion is about 4.5:1, the cross-sectional area of the bore **76** should be approximately 0.9 times the internal cross-sectional area of the flue tube **81**. This ratio is reduced, however, by the fact that the temperature of the air passing through the flue tubes **81** is approximately 1000° C., while the fuel gas passing through the bores **76** is approximately at the temperature of the quencher **50**, which is approximately 350° C. Allowing for this temperature difference, the area ratio of the bore **76** to the flue tube **81** will be approximately 0.43:1.

A further function of the flue tubes **81** is to impress a pressure drop on the gases flowing therethrough to equalize the flow through the central spaces **22** and **23** and to act as distributors for the gases to insure this result. Under the normal operating conditions required for optimum yields of acetylene, I have found that the internal diameter of the flue tubes **81** should be not less than one inch, which would give a pressure drop of about 0.175" of mercury static pressure, and could be as much as 1¼ inches, which would reduce the pressure drop to 0.109" of mercury.

In designing the quenchers **50** and **51**, the matter of heat transfer from the hot cracked gas to the quencher should be considered. For optimum quenching, the temperature of the gas should be reduced at the rate of about 20,000° C. per second or higher, and it is desirable to reduce the temperature of the gas at least 200° C. during passage through the quencher. The quantity of cracked gas to be cooled is 120 s.c.f.m. per square foot of cross-section of the interior of the furnace, and, in addition, 155 s.c.f.m. of steam must be quenched, which will require a total of 2550 B.t.u. per minute. The flue tubes **81** are spaced on 2¼ inch centers, providing 28.5 flue tubes per square foot of quencher area. Using flue tubes of one inch diameter and two inches long, the quenching area provided thereby is 1.24 square feet of face area on the quencher. However, most of the heat transfer is by radiation, and hence the faces of the quenchers **50** and **51** will transfer heat as well as the surfaces of the flue tubes **81**. The total available quenching area, therefore, is 3.24 square feet per square foot of gross area of the quencher. Since the heat transfer is proportional to $T_1^4 - T_2^4$, the transfer at 2500° R. and 1140° R., which are absolute temperatures of the gas and quencher respectively, will be 3500 B.t.u. per minute with an emissivity factor of 1.0. For dull stainless steel this factor is about 0.65, which will transfer about 2300 B.t.u. per minute. In addition, there is a convection transfer, which is about 200 B.t.u. per minute. The total is about 2500 B.t.u. per minute, and approximately the heat transfer requirement for obtaining the desired quench.

It is sometimes desirable to quench the cracked gas further than indicated above. This may be done by making the quenchers **50** and **51** thicker and the flue tubes **81** longer, or by using a larger number of smaller flue tubes, to provide more quenching surface.

It is also desirable in some cases to supply steam to the spaces **22** and **23** during the make steps to provide an additional quench. To accomplish this, during a LH make step as shown in Fig. 2, the fuel valves **43** and **44** are closed and the steam valve **44***a* is opened to supply steam at the correct pressure to the manifold **56**, the pipes **54**, and the nozzles **71** to inject steam into the space **23** countercurrent to the flow of cracked gas therethrough. Thus, the nozzles **71** may serve the double purpose of supplying fuel during the heat steps and steam for quenching during the make steps. Since the construction and arrangement of the nozzles **71** are designed for conditions required for proper fuel supply, the steam pressure must be adjusted to provide a proper supply of steam therethrough for quenching. If it is desired to obtain a steam quench of the cracked gas at 200° C., saturated steam at an initial temperature of about 150° C. is supplied through the quencher **51**, and the cracked gas mixture will be reduced from 1075° C. to 875° C. If the total volume of the cracked gas mixture is 275 s.c.f.m. it will require about 2550 B.t.u. for such quenching. The temperature of the quenching steam will be increased from 150° C. to about 875° C., which requires a flow of quenching steam of about 75 s.c.f.m., or about 11.5 s.c.f.m. per nozzle **71**, and to accomplish this will require a pressure of about 18 p.s.i.g. on the supply of quenching steam. Since the quenching steam is discharged into the spaces **22** and **23** during the make steps and countercurrent to the flow of cracked gas therein it causes a high degree of turbulence in the spaces, which quenches the cracked gas quickly as it leaves the center mass **25**. This is another advantage and object of the invention. The partially quenched cracked gas then flows through the quencher **50** or **51** where the temperature is further reduced as explained above. By these two quenches the temperature of the cracked gas can readily be reduced at least 400° C. if desired.

There are two important limitations on the operating temperatures of the quenchers **50** and **51** to insure proper operation of the furnace. First, if the fuel gas passing through the fuel pipes **54** and the orifices **77** is heated much beyond 600° C., some cracking of the fuel gas occurs to produce undesirable tars which tend to plug the orifices. Therefore, the temperatures within the quenchers should not exceed 600° C. Secondly, if the temperature in the quenchers falls below the dew point of tars in the cracked gas, such tars will deposit on the quenchers to reduce the heat transfer characteristics thereof and to tend to plug the flue tubes **81**. With cracked gases normally formed in my furnace, the dew point of such tars is normally somewhat below 300° C. and to prevent the deposit of such tars this is the minimum permissible temperature of the quenchers. Normally the furnace should be operated on heating steps only until the temperature of the quenchers **50** and **51** is raised above 300° C. before cracking is started, and thereafter the temperature of the quenchers should be maintained below 600° C.

An alternative form of nozzle element **71***a* is shown in Fig. 14 in which the only difference from the nozzle element **71***a* is in the plug **75***a*. In this form, the outer end of the plug **75***a* is closed by a wall **75***b* having a plurality of orifices **75***c* therein which are directed radially and outwardly, and the orifices **77***a* which admit gas or steam to the interior of the plug are enlarged. With this construction, fuel ejected from the orifices **75***c* crosses the path of air flowing through the flue tubes **81** and provides an improved mixing of the fuel and air during a heat step to give more uniform combustion.

From the foregoing description it will be understood that the cross-sectional area of such a furnace may be scaled up or down as desired to provide any desired furnace capacity within a wide range, providing furnace capacities greatly in excess of those attainable with conventional regenerative furnaces. This is an important object of the invention.

The transverse members **50** and **51** also serve a further purpose in acting as baffles tending to confine the pyrolysis of the in-gas during each make step to the relatively short zone therebetween, which materially increases the yield of the desired hydrocarbon.

The air passing through the member **51** is at a higher temperature than the member **51** due to having absorbed heat from the mass **17**. Some drop in temperature, therefore, occurs at this point. However, the heat exchanger **64** takes heat from both transverse members **50** and **51** and the blower **66** supplies air to the pipe **27** through the valve **32**, which adds heat to the air entering the mass **17** in amount approximately double that removed from the

air by the member **51**. Also, since these furnaces are normally operated in pairs, all of the heat removed by the members **50** and **51** of the furnace which is on the cracking cycle is added to the air supplied to the furnace on the heat cycle. Therefore, the net result is that the heat added to the air before it enters the mass **17** is four times the heat removed by the member **51** less, of course, the normal loss in heat transfer. Conversely, during the right-hand heat step, air passing through the transverse member **50** is cooled but, before entering the mass **15**, it is heated to the extent of four times this heat removal by means of the heat exchanger **64**, which transfers heat to the air supplied to the valve **31** and the pipe **26**.

While I have described a preferred embodiment of this invention, it will be apparent to those skilled in the art that its novel features may be applied in other equivalent forms, and I do not desire to be limited to such specific embodiment disclosed but desire to be afforded the full scope of the following claims.

I claim as my invention:

1. In a regenerative furnace for the pyrolysis of hydrocarbons, the combination of: a first regenerative mass; a second regenerative mass axially aligned with and longitudinally spaced from said first mass to provide a first combustion space therebetween; a third regenerative mass axially aligned with said first and second masses and longitudinally spaced from said second mass to provide a second combustion space therebetween; a first fuel injection means extending into said first combustion space and having a plurality of nozzles in said space all directed axially of the furnace and only towards said second mass; and a second fuel injection means extending into said second combustion space and having a plurality of nozzles in said space and all directed axially of the furnace and only towards said second mass.

2. In a regenerative furnace for the pyrolysis of hydrocarbons, the combination of: first and second regenerative masses axially aligned and spaced apart to provide a combustion space, each of said masses having a plurality of longitudinal gas channels therethrough communicating with said combustion space; means for injecting fuel into said combustion space, including a plurality of nozzles; and transverse baffle means in said combustion space and completely extending thereacross, said baffle means having a plurality of openings therethrough to provide communication between the channels in said first mass with the channels in said second mass, the total cross-sectional area of said openings being at least as great as the smallest total cross-sectional area of the channels in either of said masses, said openings being independent of and spaced from said nozzles.

3. In a regenerative furnace for the pyrolysis of hydrocarbons, the combination of: a first regenerative mass; a second regenerative mass spaced from said first mass to provide a first combustion space therebetween; a third regenerative mass spaced from said second mass to provide a second combustion space therebetween, each of said masses having a plurality of longitudinal gas channels therethrough communicating with the adjacent space or spaces; means for injecting fuel into each of said combustion spaces, including a plurality of nozzles; and transverse baffle means in each of said combustion spaces and extending completely thereacross, each of said baffle means having a plurality of openings therethrough to provide communication between the channels of the masses on each side of such baffle means, the total cross-sectional area of said openings in each of said baffle means being at least as great as the smallest total cross-sectional area of the channels in any of said masses, said openings being independent of and spaced from said nozzles.

4. In a regenerative furnace for the pyrolysis of hydrocarbons, the combination of: first and second regenerative masses spaced apart to provide a space therebetween, each of said masses having longitudinal gas channels therethrough communicating with said space; conveying means for conveying a cooling fluid through a predetermined confined path from the exterior of the furnace into and through said space and out of the furnace, said path being separated from gases in said space; and a heat exchanger external to the furnace and associated with said conveying means for recovering at least a part of any heat gained by said cooling fluid during its passage through said space and for cooling said cooling fluid.

5. In a regenerative furnace for the pyrolysis of hydrocarbons, the combination of: first and second regenerative masses spaced apart to provide a combustion space therebetween, each of said masses having longitudinal channels therethrough communicating with said space; fuel means for supplying fuel to said space; air means for supplying air to the end of one of said masses remote from said space; conveying means for conveying a cooling fluid through a predetermined confined and tortuous path from the exterior of the furnace into and through said space and out of the furnace, said path being separated from said space; and heat exchanger means external to the furnace and associated with said conveying means and said air means for imparting some of the heat of said cooling fluid in said conveying means to air to be supplied to the furnace by said air means.

6. In a regenerative furnace for the pyrolysis of hydrocarbons, the combination of: first and second regenerative masses spaced apart to provide a space therebetween, each of said masses having a plurality of longitudinal gas channels therethrough communicating with said space and adapted to convey gases to or from said space; a closed container extending into said space from the exterior of the furnace so as to completely fill the cross-sectional area of said space but having a thickness substantially less than the length of said space between said masses; a plurality of fuel pipes within said container; a plurality of nozzles associated with each of said fuel pipes and extending from said container towards one of said masses; means for supplying fuel to said fuel pipes so as to be ejected through said nozzles into said space; a plurality of flues associated with said container and passing therethrough to provide communication between said space on one side of said container and said space on the other side of said container; baffle means in said container for directing a flow of fluid therethrough around said nozzles and said flues; and means for supplying fluid to and removing it from the interior of said container.

7. A method of operating a regenerative furnace having two spaced regenerative masses and a space therebetween, including the steps of: heating one of said masses to a temperature adapted to crack a suitable hydrocarbon in an in-gas; conveying such an in-gas through said one of said masses, through said space, and through the other of said masses so as to crack a substantial portion of said in-gas in said one of said masses; conveying a cooling fluid in a predetermined confined and tortuous path through said space during the passage of the cracked gas through said space; and maintaining the temperature of said cooling fluid substantially below the maximum temperature of the cracked gas during the passage of said cracked gas through said space so as to cool said cracked gas substantially.

8. A method of operating a regenerative furnace having two spaced regenerative masses and a space therebetween, including the steps of: heating one of said masses to a temperature adapted to crack a suitable hydrocarbon in an in-gas and in excess of 800° C.; conveying such an in-gas through said one of said masses, through said space, and through the other of said masses so as to crack a substantial portion of said in-gas in said one of said masses, the cracked gas passing from said one of said masses into said space at a temperature in excess of 800° C.; conveying a cooling fluid in a pre-

determined confined and tortuous path through said space during the passage of the cracked gas through said space; and maintaining the temperature of said cooling fluid substantially below the maximum temperature of the cracked gas during the passage of said cracked gas through said space so as to cool said cracked gas at least 100° C.

9. A cyclic method of operating a regenerative furnace having first, second, and third regenerative masses spaced apart to form a first space between the first and second masses and a second space between the second and third masses, first quenching and fuel injection means in the first space and second quenching and fuel injection means in the second space, including the steps of: a first heating step consisting of conveying air through the first mass and into the first space, injecting a fuel gas through the first injection means into the first space, combusting the fuel gas in the first space and passing the products of combustion through the second mass, the second space and the third mass to heat the second and third masses, the fuel gas being adapted to be at least partially cracked by exposure to a predetermined elevated temperature, and maintaining the temperature of the first fuel injection means at a temperature below said predetermined elevated temperature; a first cracking step consisting of conveying an in-gas through the third mass and into the second space, through the second space and through the second mass, first space and first mass to crack the in-gas in the third and second masses to produce a cracked gas containing a desired hydrocarbon and tarlike materials and to quench the cracked gas in the first space by the first quenching means and maintaining the first quenching means at a temperature above the dew point of said tarlike materials; a second heating step consisting of conveying air through the third mass and into the second space, injecting such a fuel gas through the second injection means into the second space, combusting the fuel gas in the second space and passing the products of combustion through the second mass, the first space and the first mass to heat the second and first masses, and maintaining the temperature of the second fuel injection means at a temperature below said predetermined elevated temperature; a second cracking step consisting of conveying such an in-gas through the first mass and into the first space, through the first space and through the second mass, second space, and third mass to crack the in-gas in the first and second masses to produce such a cracked gas and to quench the same in the second space by the second quenching means, and maintaining the second quenching means at a temperature above the dew point of said tarlike materials in the cracked gas; and repeating said steps.

10. In a regenerative furnace for the pyrolysis of hydrocarbons, the combination of:

first and second regenerative masses spaced apart to provide a space therebetween, each of said masses having a plurality of longitudinal gas channels therethrough communicating with said space and adapted to convey gases to or from said space;

a transverse member in said space and completely filling the cross-sectional area of said space but having a thickness substantially less than the length of said space so that the member is spaced from each of said regenerative masses;

a plurality of uninterrupted flues through said transverse member, each of said flues providing communication through said transverse member from one side to the other side thereof, said flues being evenly distributed throughout the cross-sectional area of the transverse member; and

passage means for conveying a cooling medium through the interior of said transverse member and adjacent to said flues to cool said transverse member and said flues.

11. In a regenerative furnace for the pyrolysis of hydrocarbons, the combination of:

first and second regenerative masses spaced apart to provide a space therebetween, each of said masses having a plurality of longitudinal gas channels therethrough communicating with said space and adapted to convey gases to or from said space;

a transverse member in said space and completely filling the cross-sectional area of said space but having a thickness substantially less than the length of said space so that the member is spaced from each of said regenerative masses;

a plurality of uninterrupted flues through said transverse member, each of said flues providing communication through said transverse member from one side to the other side thereof, said flues being evenly distributed throughout the cross sectional area of the transverse member;

a plurality of nozzles associated with said transverse member, said nozzles being evenly distributed throughout the cross-sectional area of said member and independent of said flues, said nozzles being adapted to direct a fluid flow from the interior of said transverse member into said space on one side of said member;

means for supplying a fluid flow through said transverse member to said nozzles; and

passage means for conveying a cooling medium through the interior of said transverse member and adjacent to said flues and nozzles to cool said transverse member and said flues and nozzles.

12. In a regenerative furnace for the pyrolysis of hydrocarbons, the combination of:

first and second regenerative masses spaced apart to provide a space therebetween, each of said masses having a plurality of longitudinal gas channels therethrough communicating with said space and adapted to convey gases to or from said space;

a transverse member in said space and completely filling the cross-sectional area of said space but having a thickness substantially less than the length of said space so that the member is spaced from each of said regenerative masses;

a plurality of uninterrupted flues through said transverse member, each of said flues providing communication through said transverse member from one side to the other side thereof, said flues being evenly distributed throughout the cross-sectional area of the transverse member;

passage means for conveying a cooling medium through the interior of said transverse member and adjacent to said flues to cool said transverse member and said flues;

supply means for supplying gaseous material to the end of said first regenerative mass remote from said space; and

heat exchanger means external to the furnace, said passage means and said supply means passing through said heat exchanger means in heat exchange relationship so that heat from the cooling medium in said passage means is transferred to said supply means to heat gaseous material therein and to cool said cooling medium.

13. A method of operating a regenerative furnace having two spaced regenerative masses and a space therebetween, including the steps of:

heating one of said masses to a temperature adapted to crack a suitable hydrocarbon in an in-gas and in excess of 800° C.;

conveying such an in-gas through said one of said masses, through said space, and through the other of said masses so as to crack a substantial portion of said in-gas in said one of said masses, the cracked gas passing from said one of said masses into said space at a temperature in excess of 800° C.;

conveying a cooling liquid in a predetermined confined and tortuous path through said space during the passage

of the cracked gas through said space, said cooling liquid having a boiling point substantially above 260° C.; and

maintaining the temperature of said cooling liquid substantially below the maximum temperature of the cracked gas during the passage of the cracked gas through said space so as to cool said cracked gas at least 100° C., the temperature of the liquid being maintained above 260° C. and below the boiling point of the liquid.

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