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FURNACE ASSEMBLIES AND COMBINATION OF SUCH FURNACES

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FIG. I.

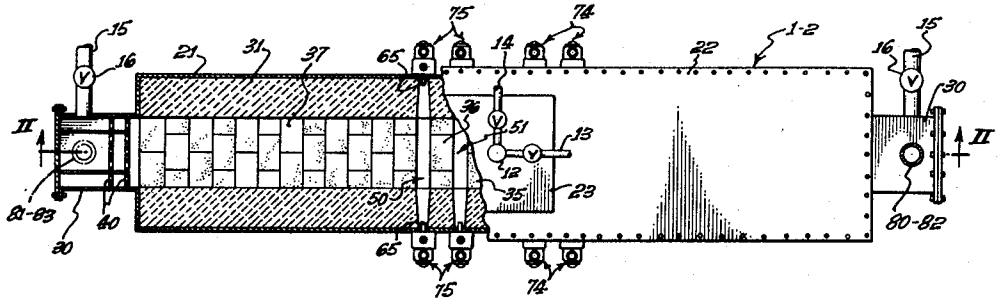


FIG. II.

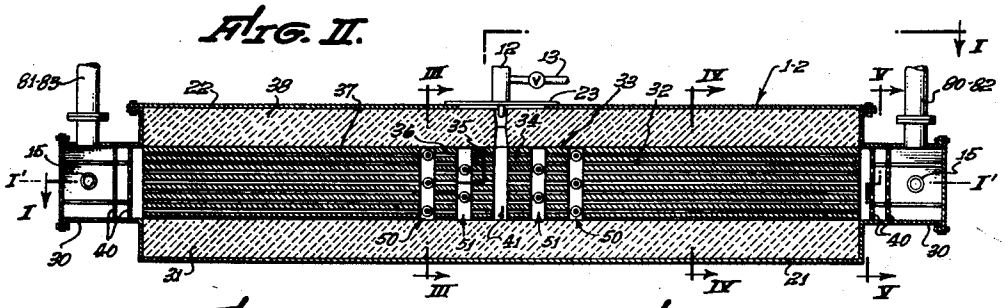


FIG. III.

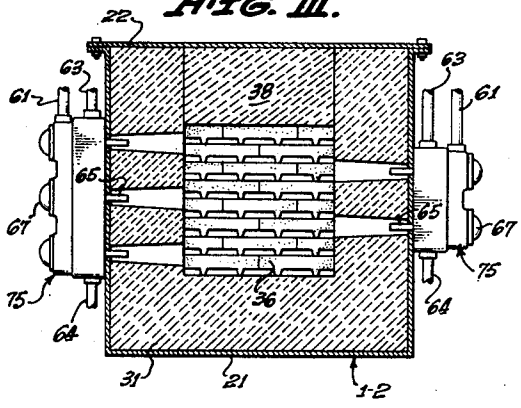


FIG. IV.

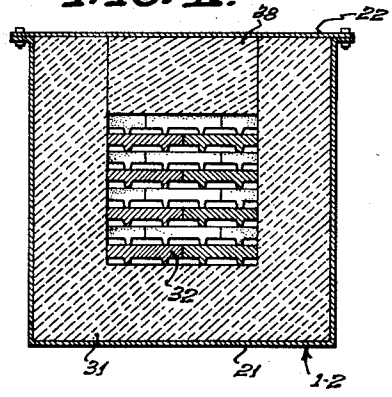
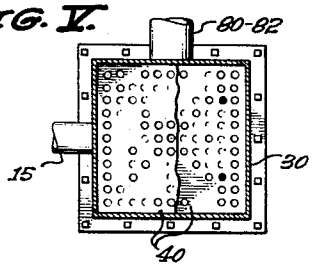


FIG. V.



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FIG. VI.

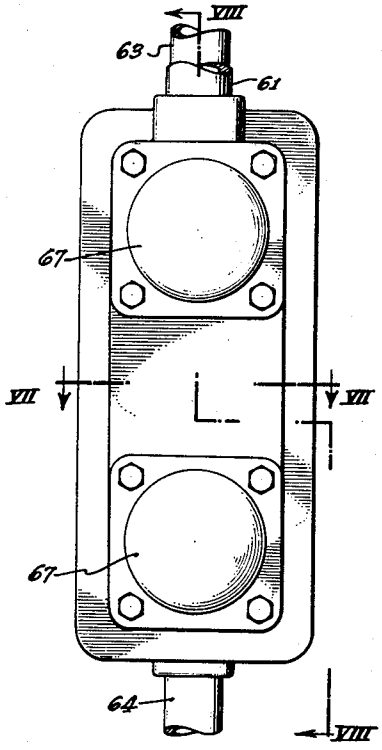


FIG. VIII.

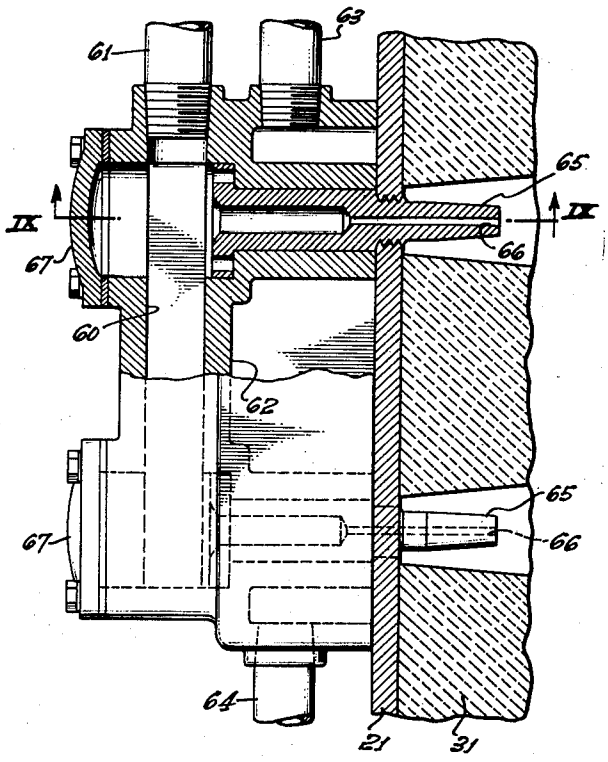


FIG. VII.

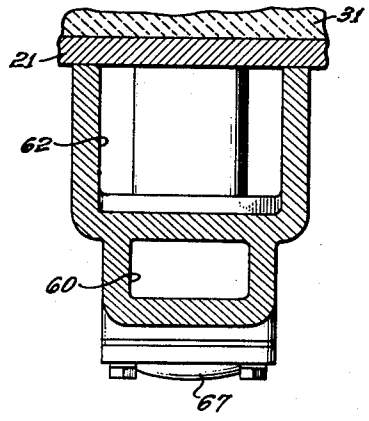
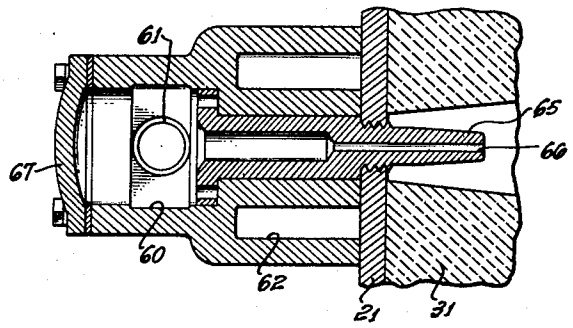


FIG. IX.



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FIG. X.

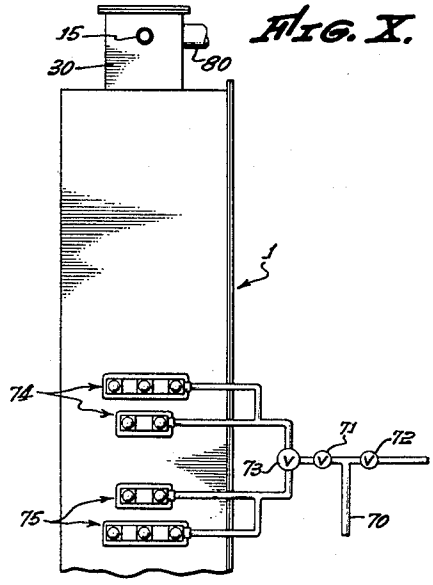


FIG. XI.

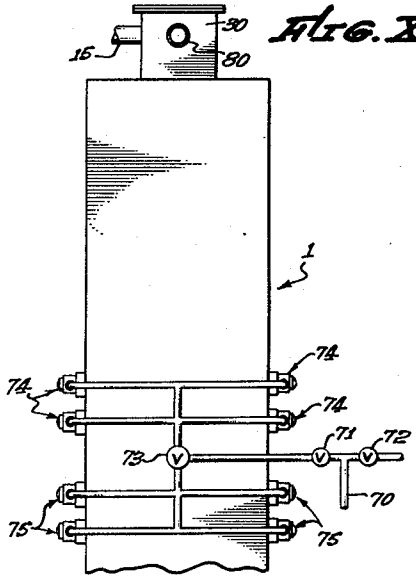


FIG. XX.

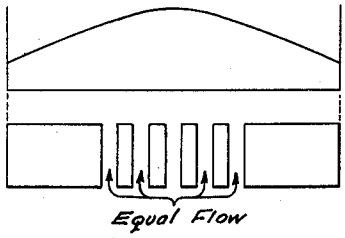


FIG. XXI.

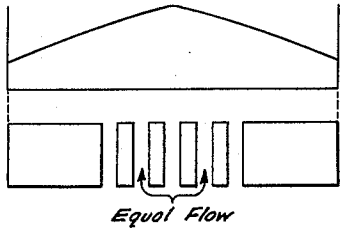


FIG. XXII

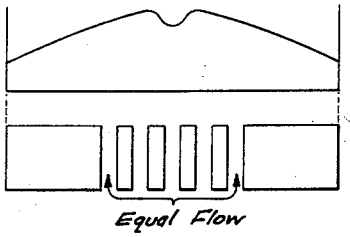
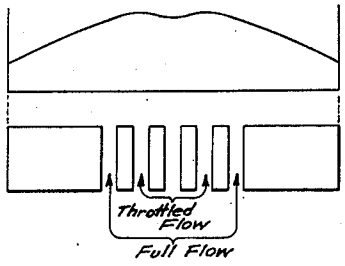


FIG. XXIII.



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FIG. XII.

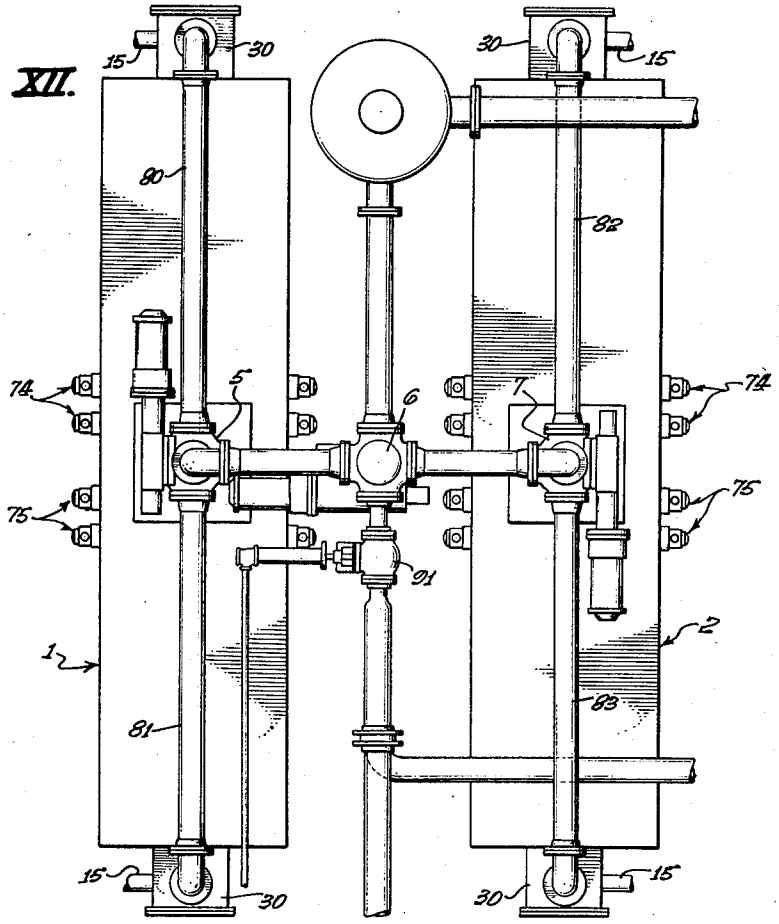
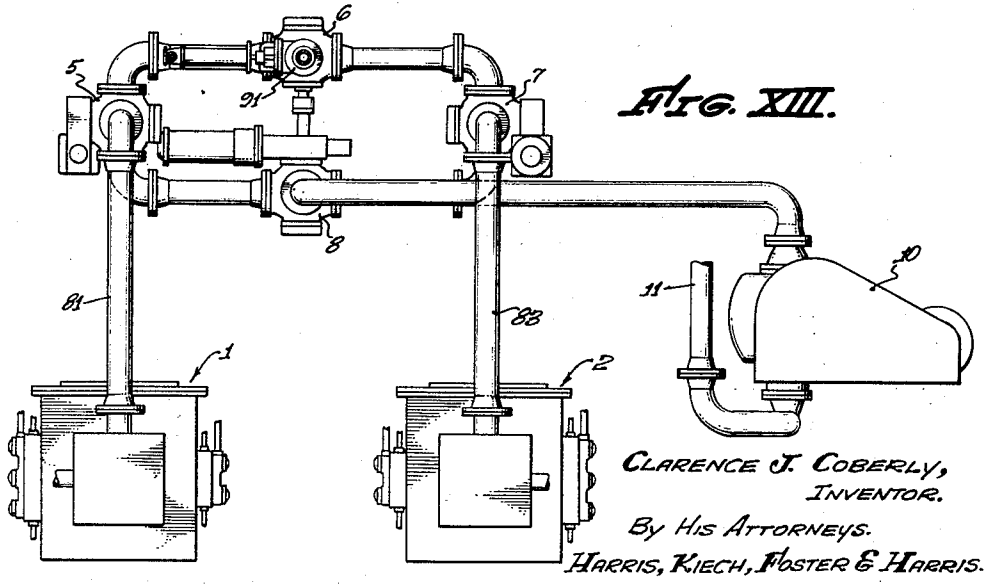


FIG. XIII.



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FURNACE ASSEMBLIES AND COMBINATION OF SUCH FURNACES

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FIG. XIV.

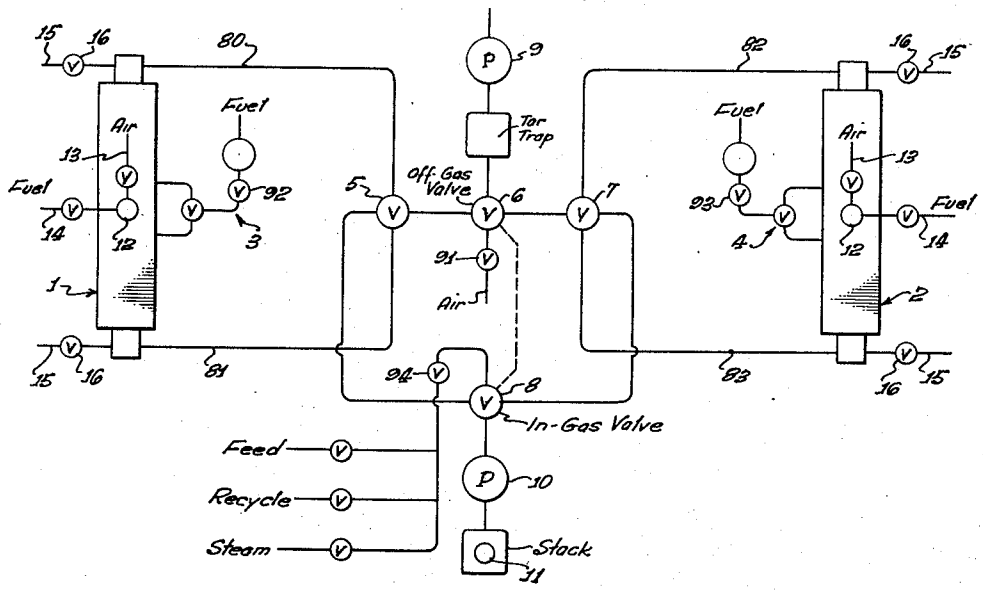
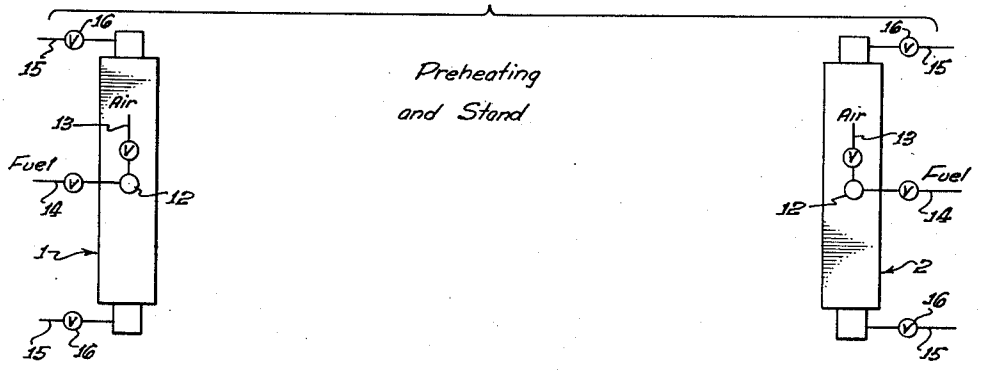


FIG. XV.



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FURNACE ASSEMBLIES AND COMBINATION OF SUCH FURNACES

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FIG. XVI.

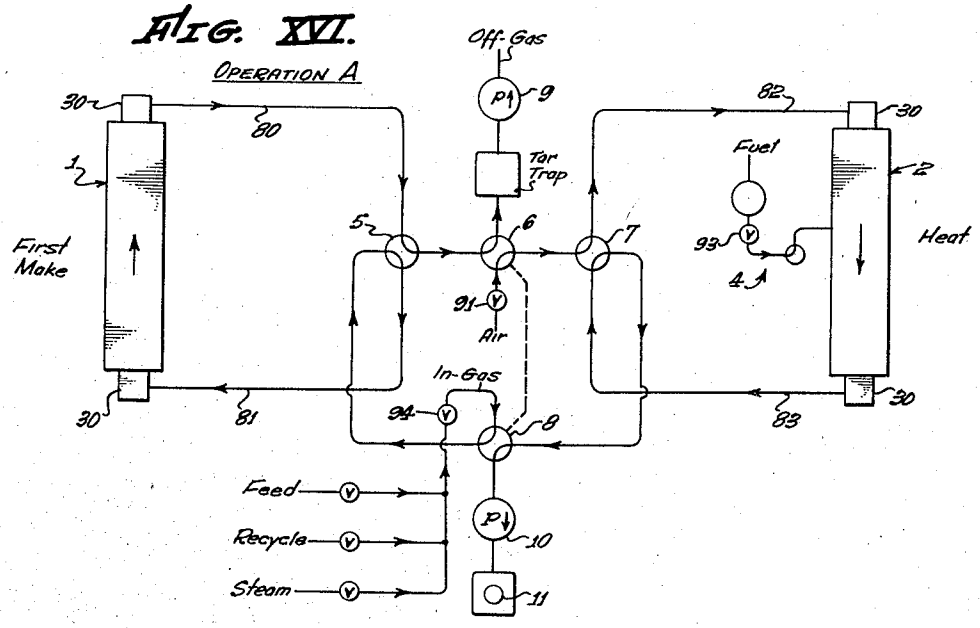
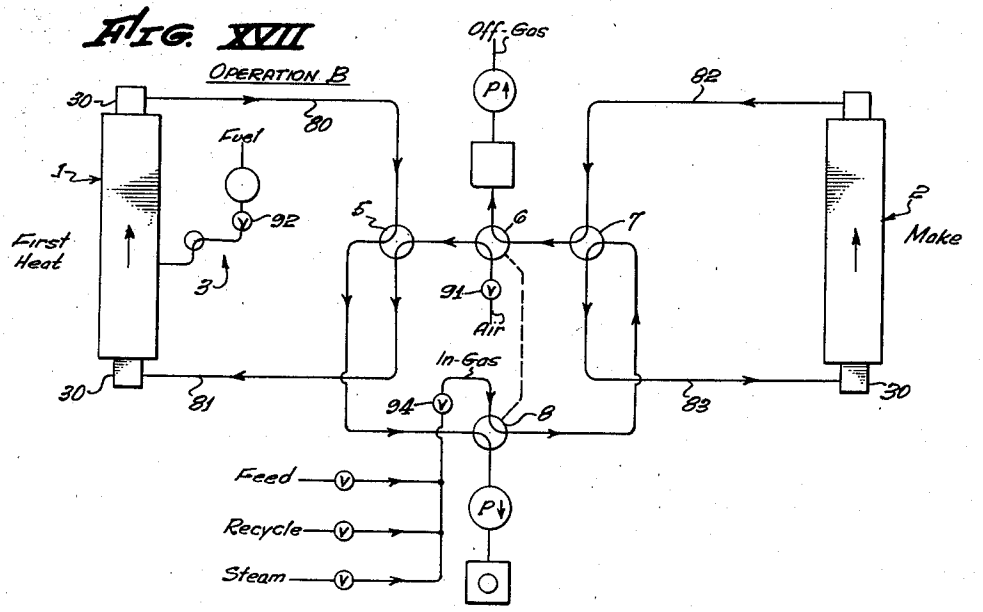


FIG. XVII



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FIG. XVIII.

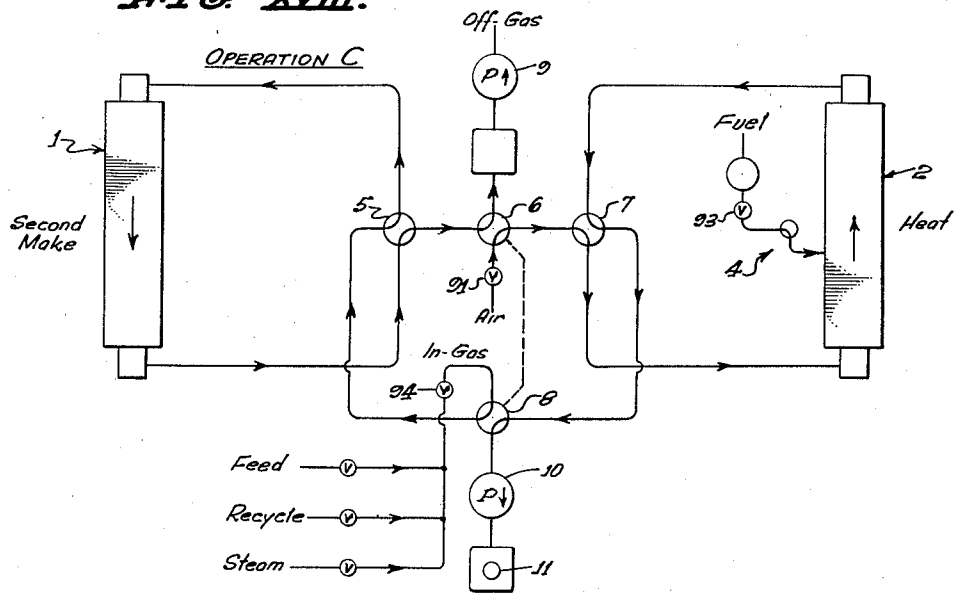
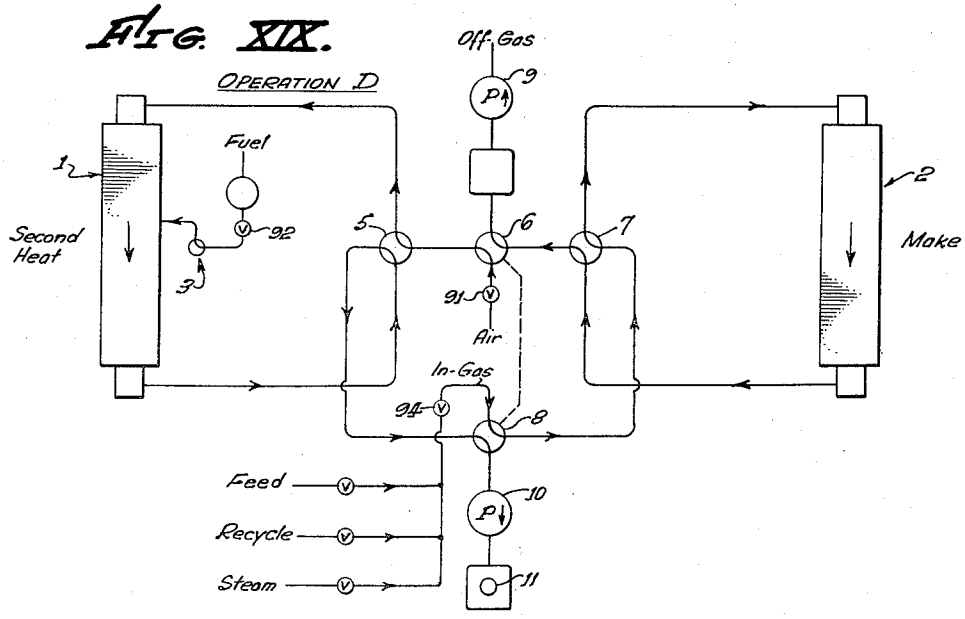


FIG. XIX.



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FIG. XXIV

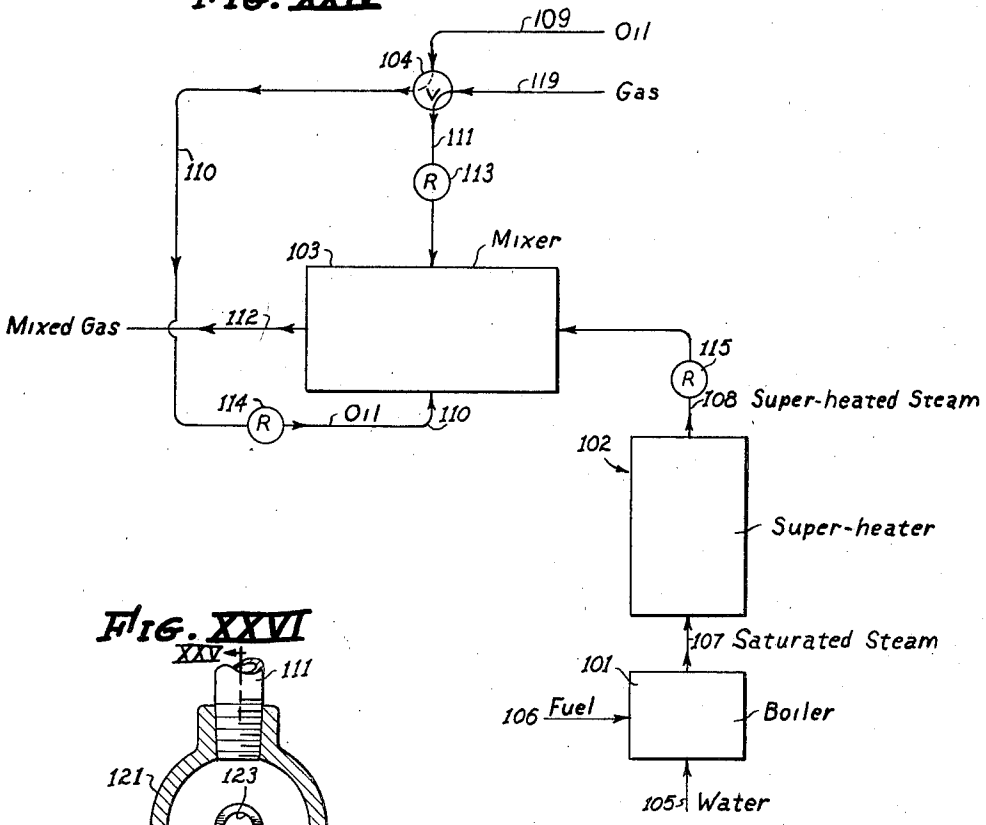


FIG. XXVI

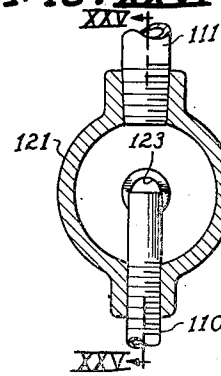
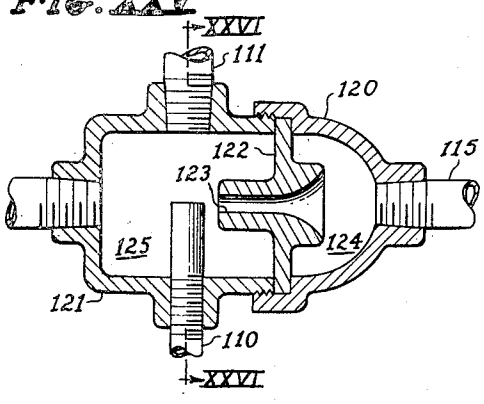


FIG. XXV



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United States Patent Office

2,956,864

Patented Oct. 18, 1960

2,956,864

FURNACE ASSEMBLIES AND COMBINATION OF SUCH FURNACES

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

Filed Jan. 10, 1955, Ser. No. 480,794

4 Claims. (Cl. 23—277)

The inventions claimed herein may be briefly summarized as embodied in a new and useful furnace having at least two regenerative masses which is operated in such a manner as to produce desired hydrocarbons from suitble hydrocarbons with a high heat economy and with a maximum possible yield of the desired hydrocarbon.

These inventions are further embodied in an assembly of two such furnaces with auxiliary apparatus, this assembly having a high heat economy and efficiency. In these furnaces the heat needed to produce certain desired reacions is supplied by contact of the suitable hydrocarbon with surfaces of the highly heated regenerative masses during a "make" step, these masses being heated by products of combustion during a "heat" period.

In any interpretation of the claims, the following definitions should apply.

The term "regenerative mass," as used herein, is limited to and defined as a mass of material capable of resisting material damage at temperatures in excess of 2000° F. and which has small channels through which gases are passed in the operation of the apparatus hereinafter described.

The word "pyrolysis" is used in its dictionary meaning as "a chemical decomposition by the action of heat." The word "cracking," is used herein to denote a pyrolysis of hydrocarbons which is not carried to the point of decomposing the hydrocarbons to carbon and hydrogen, but one in which new compounds are formed and hydrogen is released.

The hyphenated word "in-gas," as used herein, is limited to and defined as the gas which enters a furnace where it is subjected to pyrolysis and which is a suitable hydrocarbon, or which contains a substantial amount of a suitable hydrocarbon.

The words "substantial amount" are used herein to denote the percentage of a designated gas contained in a mixed gas and are limited to a percentage of more than two percent by volume of the designated gas.

The words "suitable hydrocarbon," as used herein, denote any hydrocarbon which is stated in the art to be, or which is, capable of producing an off-gas containing a desired hydrocarbon by pyrolysis of said in-gas. Natural gas, or the vapors of natural gasoline, off-gases from refineries or coking plants, and gas mixtures containing a substantial proportion of methane, ethane, propane, butane or the like are all suitable in-gases.

The hyphenated word "off-gas" is used herein to designate a mixed gas which has been subjected to pyrolysis in the apparatus hereinafter described and which contains a substantial amount of a desired hydrocarbon.

The words "desired hydrocarbon" are used herein to denote any hydrocarbon which can be produced in the apparatus by the pyrolysis of a suitable hydrocarbon. The apparatus described hereinafter was designed and is well adapted to produce an off-gas containing a substantial proportion of acetylene and the method by which such an off-gas may be produced is the best mode which I now contemplate for use of the invention. I do not

thereby waive any right to use the apparatus for other uses or purposes.

Objects and advantages of the invention will be set forth in detail at appropriate points in the following specification.

In the drawings, which illustrate the invention:

Fig. I is a plan view of a new and novel furnace embodying my invention, the upper portion being broken away as indicated by the line I—I in Fig. II, to better illustrate the internal structure.

Fig. II is a central elevational section of the furnace shown in Fig. I, this section being on a plane indicated by the line II—II in Fig. I.

Figs. III, IV and V are cross sections of the furnace shown in Figs. I and II, these sections being on planes indicated by the lines III—III, IV—IV and V—V in Fig. II.

Fig. VI is an elevation of a two-nozzle fuel gas manifold. One of these manifolds is placed on one side of a furnace and a three-nozzle manifold, not shown, is placed on the other side of the furnace.

Fig. VII is a section on a plane defined by the line VII—VII of Fig. VI.

Fig. VIII is an elevation showing one side of the fuel manifold shown in Fig. VI, this view being partly in section on a plane defined by the line VIII—VIII of Fig. VI.

Fig. IX is a section of the same manifold, the view being in section on a plane defined by the line IX—IX of Fig. VIII.

Fig. X is a side view of a portion of one of the furnaces shown in Fig. I which shows the fuel manifolds and fuel supply piping.

Fig. XI is a plan view of the apparatus shown in Fig. X. The fuel manifolds and piping therefor are rather complicated and are wholly or partially omitted in some figures.

Fig. XII is a plan view of an assembly of two furnaces similar to the furnace previously described showing some of the valves, piping and other auxiliaries.

Fig. XIII is an elevation of the apparatus shown in Fig. XII.

Fig. XIV is a diagrammatic sketch showing some of the apparatus used in the furnace assembly.

In the succeeding figures, which show separate steps in the method of operation, only those parts of the apparatus which are used in any step are shown in the figure disclosing said step.

Fig. XV is a diagrammatic sketch showing how the apparatus is used to preheat the furnaces or to keep them hot when they are not in active use.

Figs. XVI, XVII, XVIII and XIX are diagrammatic views each showing how the apparatus is operated in one of the four cyclic steps A, B, C and D, as hereinafter described.

Figs. XX, XXI, XXII and XXIII show the distribution of temperature in the mixing zone with different distribution of flow from the heating system.

Fig. XXIV is a diagram showing the apparatus needed when using a liquid hydrocarbon (or oil) as a suitable hydrocarbon.

Fig. XXV is a central section of the mixer on a plane represented by the line XXV—XXV in Fig. XXVI.

Fig. XXVI is a section of the mixer on a plane represented by the line XXVI—XXVI in Fig. XXV.

The complete apparatus, as diagrammatically indicated in Fig. XIV, consists of two furnaces **1** and **2** which are duplicates. Furnace **1** has a fuel supply system **3** and furnace **2** has a fuel supply system **4**. Connected to the furnaces **1** and **2** are four four-way valves **5**, **6**, **7** and **8**. The apparatus also includes an off-gas pump **9** and products of combustion gas pump **10** which delivers such flue

gas to a stack or chimney **11**. Each furnace has a burner **12** supplied with air from a pipe **13** and fuel gas under the pressure from a pipe **14**, and mixed gas may be passed through an opening in the cover into the center combustion chamber of the furnace. Each end of each furnace has a small stack pipe **15** having a valve **16**. The pipes **15** and valves **16** are used only in a preheating or standby step in the process, hot gases being used in the cyclic operation of the apparatus, and they are shown only in Figs. I, XIV and XV.

The furnaces, as shown in Figs. I and II, consist of a steel shell **21** which is made in the form of an open box **21** with a flanged top upon which a cover **22** is bolted, the assembled box with its cover being made of sufficiently heavy steel to withstand a full vacuum. The cover is sufficiently tight to insure such a vacuum being maintained in the shell **21** with the cover **22** in place. In the larger furnace, a small cover **23** closes a manhole in the center of the cover **22**. See Figs. I and II.

Projecting beyond each end of each of the furnaces **1** and **2** is an extension **30**. The inside of the box **21** is lined with a heat resisting lining **31** forming a trough and regenerative masses **32, 33, 34, 35, 36** and **37** are produced by stacking up tiles in the trough, as shown in Figs. IV, III and II. These tiles may be similar to the tile shown in Patent No. 2,473,427, patented June 14, 1949, to R. L. Hasche, the tile being, however, laid flat so that horizontal ducts are formed extending along the major axis, indicated by the lines I—I′ of Fig. II and II—II of Fig. I. The ducts provide channels having open paths through the masses **32–37**, inclusive, from the extension **30** on one end, to an extension **30** on the other end of the furnace. After the tiles are laid, a heat resisting top lining **38** is laid and the cover **22** is bolted in place. Each of the extensions **30** is provided with distribution plates **40**, as shown in Figs. I, II and V, and each of the plates is provided with small holes. These holes should be of a size to cause a pressure drop through one set of distribution plates **40** of about four inches of water when the gas flow is normal. If this pressure drop is maintained, the distribution of flow of gases through the channels of the regenerative mass will be quite uniform.

The primary requirement of the regenerative masses **32** to **37** inclusive is to provide a large heat storage mass and good heat transfer between the gas and the mass. This means that the area of the passages should be as small as possible without causing an excessive pressure drop when gas is flowing through the mass at the maximum rate. It has been found that this condition is satisfied when the area of the passages is approximately 25% of the gross cross section of the mass.

The gross cross section required for a given capacity should be about .048 sq. ft. per cu. ft. of propane fed per min., or .080 sq. ft. per cu. ft. of acetylene produced per min. with twin furnaces in which the flow is continuous. With masses of the proportions given above, the open passage through the masses should be about .011 sq. ft. per cu. ft. of propane fed or about .019 sq. ft. per cu. ft. of acetylene produced.

With masses of the above proportions and with a length which will limit the exit temperature to a value slightly above the temperature at which tars start to deposit in the channels, the maximum pressure drop through the furnace and the associated piping should be about 1½″ Hg on the heat cycle and 1″ Hg on the cracking cycle.

The regenerative tiles are stacked in the channel provided between the insulating side walls of the furnace. Half length tiles are provided to permit staggering the joints and prevent any accumulated error in the alignment of the passages. No cement is used as it has been found that the tiles will not be displaced in operation when they are installed in this manner which makes it easy to install or replace tiles and they may be removed without damage to the tiles.

The material which has been found suitable for regenerative masses is high purity "Alundum" (over 99% Al_2O_3) or silicon carbide, or other highly stable high temperature ceramics. High purity "Alundum" is the preferred material as it has been found to be very stable at the required operating temperatures of 800° C. to 1500° C. and the heated surface of this material promotes the production of acetylene. It is not known whether or not "Alundum" has a catalytic effect but it has been found to operate in this apparatus at lower temperatures than those reported in the art.

It has been found that "Alundum" brick of approximately the same composition as the masses should be used adjacent to the masses in that part of the furnace in which the temperature is over 800° C. This extends each way from the middle of the furnace with the furnace arrangement shown in Figs. I and II.

The various regenerative masses may be divided in various ways. It is desirable to have at least two central masses like **34** and **35**, thus leaving a central combustion space **41** into which the burner **12** may feed a combustible mixture during the heating period and to keep the furnace hot during shutdowns. During the preheating period, as shown in Fig. XV, the pumps **9** and **10** are shut down, the valves **16** are open and air and fuel gas are supplied to the burners **12** through the pipes **13** and **14**, and combustion flue gases are vented through the valves **16**. When the cold furnace is heated to a temperature of about 1500° F. the valves **16** are closed and the supply of air and fuel is shut off to the burners **12**. During the cyclic operation the burners **12** are inactive and sealed to the admission of air or fuel so that a vacuum may be maintained in the system.

The masses **33** and **36** are optional so that there may be only two intermediate masses **34** and **35** between the masses **32** and **37**. In the arrangement of regenerative masses shown in Fig. II an intermediate space **50** is shown at each end of the central portion, one adjacent to the inner face of the mass **37** and the other adjacent to the inner face of the mass **32**. Two spaces **51** are also provided as shown. Each of the spaces **50** and **51** is fed with fuel through a fuel supply system such as that shown in Figs. X and XI through manifolds shown in Figs. VI, VII, VIII and IX. Referring to these figures, each manifold consists of a casting having a channel **60** fed by a fuel pipe **61** and a water channel **62** fed with circulating water which enters the channel **62** through a pipe **63** and leaves the channel **62** through a pipe **64**. Each space **50** and **51** is fed by five nozzles, three on one side and two on the other, the two nozzles on one side being horizontally disposed so that they inject a stream of fuel between the streams from the three nozzles on the other side of the furnace. This provides a very uniform mixing and combustion with the hot air fed into the spaces **50** and **51**, as will later be more fully explained.

Each manifold contains two or three nozzle members **65**, as shown in Figs. VIII and IX. The gas emerges from the inner end of each nozzle as a relatively high speed jet from a constricted orifice **66**. Covers **67** bolted to the manifold give access to openings through which individual jet members **65** may be inspected. It has been found that to obtain satisfactory mixing of the gas and air, the gas must be conducted close to one of the regenerative masses and released in a small stream of high velocity. The heated air should leave the upstream mass at a velocity of approximately 150 f.p.s. and a temperature of about 1800° F. In order to get good mixing, the velocity of the fuel gas leaving the nozzle should be at sonic velocity which requires that the pressure in the gas manifolds should be atmospheric pressure or higher when the furnace operates at 15″ of vacuum.

The piping system for the fuel nozzles **65** is shown in Figs. X and XI. Fuel under pressure is delivered to two valves **71** and **72** from a fuel supply pipe **70**. One valve **71** feeds furnace **1** and valve **72** feeds furnace **2** (not

shown). From the valves 71 and 72 the gas passes to two three-way valves 73, only one of which is shown in Fig. X since the fuel distribution is shown only for furnace 1 in that figure. This three-way valve 73 may be turned to either feed an upper series 74 of nozzles (as seen in Fig. X) or a lower series 75, each series consisting of ten nozzles 65, five on one side and five on the other side of the furnace. The upper series of nozzles 74 feeds spaces 50 and 51 adjacent to the masses 32, 33 and 34 and the lower series feeds the spaces 50 and 51 adjacent to the masses 35, 36 and 37.

Figs. XII and XIII show two elevations of the main piping actually used in the cyclic operation of the process and Fig. XIV shows diagrammatically the same apparatus. This main piping includes pipes 80, 81, 82 and 83 connected as shown in Fig. XIV.

The apparatus operates on a preliminary heating step used only after the furnace has been standing inoperative for at least several hours. This preliminary heating step is followed by a repetitive cycle consisting of four steps which, for convenience, we will call steps A, B, C and D.

The preheating step is quite independent of the cyclic operation and uses only the apparatus shown in Fig. XV, each furnace being heated independently of the other. It is important that the furnaces be heated slowly and evenly by carefully controlled combustion produced in the furnace by the burners 12. The only regenerative material which I now consider suitable is ceramic; that is, it is produced by the firing of a suitable material in a kiln or the like. Such material can be injured by too rapid heating or cooling when used in the process herein described. Therefore, the preheating is produced by feeding a suitable fuel oil or gas to the burners 12, the combustion being controlled to produce as complete a combustion as possible. The combustion mixture is fed from the burners 12 into the central combustion space 41 between the masses 34 and 35. The hot products of combustion flow slowly through all the channels of all masses into the extensions 30 and escape at a pressure slightly above atmospheric through the pipes 15, the valves 16 being open. The pumps 9 and 10 are not operating during the preheating step and there is no draft pulling these products of combustion into the main piping. The preheating step should be continued until the masses 34 and 35 of each furnace are at a temperature of 1500° F., or above. It is highly desirable that during preheating no free oxygen is introduced into the main piping to avoid later explosions during cyclic operation. When the furnace is sufficiently heated, the valves 16 are tightly closed and the valves 14 and 13 feeding fuel and air to the burners 12 are also tightly closed. The distribution of heat in the regenerative masses at the end of the preheating step may not be that desired for maximum production during cyclic operation, but the cyclic operation quickly establishes a proper distribution of heat. After the valves above designated are closed, the pumps 9 and 10 are started, thus establishing a vacuum inside the furnaces 1 and 2 and starting cyclic operation.

In starting the cyclic operation, which may continue for days at a time, it is not important which of the steps A, B, C or D is started first. At the time of starting the cyclic operation, the heat in the furnaces due to preheating may not be distributed exactly enough to give the best operation but in a very short time the cyclic operation will insure proper distribution of heat. During cyclic operation one furnace is producing an off-gas containing the desired hydrocarbon in a "make" step while the other furnace absorbs heat from hot gases of combustion in a "heat" step.

The operation during the A step, as illustrated in Fig. XVI, is as follows:

Furnace 2 is operating on a "heat" step, cold air being delivered through valves 6 and 7 and pipe 82 to an extension 30 of the furnace 2, which is shown in Figs. I and II. This cold air is heated in mass 32 to a temperature preferably above the ignition temperature of the fuel delivered through nozzles 65 to the spaces 50 and 51 adjacent to the mass 33. A rapid and complete combustion should occur and hot gases of combustion should pass to and through the mass 37 into the extension 30 and through the pipe 83 and valves 7 and 8 and the pump 10 to the stack 11. During this operation, the mass 32 is cooled and masses 33, 34, 35 and 36 are heated. The hot products of combustion are cooled in the mass 37 and a substantial proportion of the heat of the products of combustion is stored in the mass 37 and thereby saved for future use.

At the same time that the furnace 2 is being heated in a "heat" step, in operation A the furnace 1 is producing an off-gas containing a substantial proportion of acetylene in a "make" step, which operates as follows. At the beginning of the "make" step in operation A, the mass 37 is substantially hotter than mass 32 since it has been heated in a previous "heat" step. Sufficient heat has then been stored in the masses 33, 34, 35 and 36 to heat the cold in-gas up to a reaction temperature and to further supply the necessary heat to produce the desired off-gas by the endothermic reaction to acetylene.

Referring again to Fig. XVI, during the "make" step in operation A, and, in fact, in any "make" step, an in-gas is prepared by mixing a feed gas, or a recycle gas, both containing a suitable hydrocarbon, or both such feed and recycle gases, in varying proportions, with a diluent, preferably steam. This in-gas is delivered through valves 8 and 5 and the pipe 81 to an extension 30 of furnace 1 and to the masses 37, 36, 35, 34, 33 and 32 to an extension 30 of the furnace 1, pipe 80, and through the valves 5 and 6 to the pump 9 which delivers an off-gas containing a substantial proportion of acetylene. In its passage through the masses of furnace 1, the in-gas is first heated to a reaction temperature and heat is then supplied, from the masses 36 to 33, inclusive, sufficient to produce the desired reaction of the in-gas to the off-gas. The off-gas is then cooled by the relatively cold mass 32. During the entire cyclic process, the interior of both furnaces is maintained at a vacuum of about 15 inches of mercury.

In steps B, C and D the "make" and "heat" steps also occur simultaneously, the "heat" step occurring in one furnace while the "make" step occurs in the other. The valves 6 and 8 are so connected or interlocked that air cannot ever be mixed with in-gas or off-gas.

In operation B, shown in Fig. XVII, in-gas is fed through valves 8 and 7 and pipe 83 into the furnace 2 in which an off-gas is formed in a "make" step, this off-gas being withdrawn through pipe 82 and valves 7 and 6 by the pump 9. At the same time furnace 1 is being subjected to a "heat" step by fuel supplied by fuel system 3 to the spaces 50 and 51 adjacent to the mass 36, hot air being supplied to this space 50 through the mass 37, the pipe 81 and the valves 5 and 6.

In operation C, as shown in Fig. XVIII, acetylene is making in the furnace 1 while furnace 2 is heating and in Fig. XIX furnace 1 is heating and furnace 2 is making. The "heat" step and the "make" step are each separately controlled in each furnace. Two separate exhaust pumps are provided, the treated off-gas from each "make" step being always pulled out of the furnaces by the pump 9 and the cooled gases of combustion from the "heat" step being always pulled out of the furnace by the pump 10. The characteristics of each pump may be suited to the service which they render. The pressure at which the gases enter the furnaces is also separately controlled by pressure regulating valves. Valve 91, which is in the pipe to valve 6, throttles the air admitted to each furnace during its heat step to produce the required vacuum. Valve 92 controls the pressure of fuel admitted to furnace 1 and valve 93 admits fuel to furnace 2. By controlling the speed of pump 10

and the valves 91, 92 and 93, the degree of vacuum and combustion in each furnace may be controlled. Similarly, the vacuum and temperature in each furnace may be controlled by the valve 94 and the pump 9. The pressure regulating valves 91, 92, 93 and 94 are usually set during cyclic operation and once set are not disturbed. It is most important that separate controls be established on each furnace so that maximum operating efficiencies can be established in both the "heat" and "make" steps. The valves 6 and 8 being mechanically connected to turn together, neither air nor combustion gases can get into the off-gas and propane cannot be wasted in the stack 11. The partial pressure on the suitable hydrocarbon is, of course, lower than the pressure on the mixed gases, due to this mixture and to the presence of the diluent. These particulars are more pertinent to a process which will be described and claimed in a separate application therefor, but it should be borne in mind that the apparatus has no real utility unless it produces acetylene below a very difinitely fixed and maintained cost per pound of acetylene. This cost and the corresponding market prices at which acetylene can be bought in cylinders or bulk or produced by calcium carbide are a direct function of the cost of producing calcium carbide from which practically all acetylene now used in the United States is produced. It is very easy to produce acetylene from suitable hydrocarbons, particularly petroleum gases or gases containing suitable hydrocarbons, but it is difficult even where low cost suitable gases are available as charging stocks to produce acetylene at a cost competitive with hydrocarbons. I have found that to produce acetylene from any suitable hydrocarbon which I have found available in an apparatus such as has been previously described, the apparatus must have certain characteristics which will now be disclosed.

It is highly desirable that the furnaces be designed and equipped to process in-gases containing various suitable hydrocarbons in various proportions. The arrangement of regenerative masses shown in Figs. I and II make the furnaces adaptable to handling such variables in gases.

It should be noted that a separate set of fuel injection nozzles is provided at each side of the center of the furnace. The temperature gradient along the line of flow of gas being cracked is very important to the efficiency of the operation. Each of the sets of fuel injection nozzles is provided with a throttle valve to control the distribution of gas to each bank of fuel jets. Having once established the flow distribution desired, then the orifice size of the fuel injection nozzles may be altered to establish this same flow ratio with the throttle valves open.

To better describe these temperature profile control features, Fig. XX shows the temperature profile with all jets of equal size and with both throttle valves open. Under this condition, the amount of fuel in each of the two injection points will be equal. This method of feeding the fuel gas will make a very smooth profile with a broad peak, as shown. It should be noted that the zone at high temperature is thus spread and the contact time at high temperature is increased.

If the throttle valves in the outer set of fuel jets is closed off and the same total amount of fuel is added through the jets nearest the middle of the furnace, the results shown in Fig. XXI will be obtained. It should be noted in this case that the maximum temperature is higher and that the peak is much sharper. This arrangement, therefore, will subject the gas being cracked to a higher temperature but for a shorter length of time. This is advantageous with some feed stocks, particularly where a single component material is supplied, such as propane or ethane, as compared with natural gas which is a mixture of hydrocarbon gases, each having different reacting characteristics. In this case, the temperature and time factors may be controlled to give the highest yield for the particular feed stock used.

Fig. XXII illustrates the temperature profile obtained with all of the fuel fed to the outer bank of jets. In this case, two peaks will be formed, as shown, the amount of drop-off of temperature depending upon the amount and nature of the feed stock. Since heat is being absorbed as the reaction takes place and acetylene is formed, heat is removed from the center section and the temperature will be substantially lowered.

If both sets of jets are used and the amount of fuel properly adjusted, the heat input and the heat absorbed may be equalized to give a temperature profile shown in Fig. XXIII.

This is advantageous with mixed feed as it is desirable to hold the gas at a predetermined temperature for a certain time with both of these factors under definite control.

It will thus be seen that the previously described arrangement of regenerative masses and fuel nozzles in the furnace assemblies is available for processing various suitable hydrocarbons.

The preceding description assumes that the hydrocarbon used as feed stock is a gas at atmospheric temperature and pressure. If it is desired to produce acetylene or ethylene by the process or in the apparatus previously described from a hydrocarbon which is a liquid at atmospheric temperature and pressure, certain additional apparatus and a different method become necessary. The gas delivered to the furnace must then contain a hydrocarbon gas or vapor, produced from a liquid hydrocarbon such as gas oil or the like. The gas so delivered should also contain a substantial proportion of steam.

The necessary apparatus for using a liquid hydrocarbon as a raw material in the furnace is shown in Figs. XXIV, XXV, and XXVI and includes a conventional type of boiler 101, a superheater 102, a mixer 103 and a valve 104.

Water is delivered to the boiler 101 through a pipe 105 and fuel is delivered to the boiler 101 through a pipe 106. Saturated steam is delivered to the superheater 102 through a pipe 107 and superheated steam is delivered from the superheater 102 through a pipe 108 to the mixer 103. The liquid hydrocarbon, for convenience called "oil," may be delivered to the valve 104 through a pipe 109 and through valve 104 and a pipe 110 to the mixer 103.

It is sometimes desirable to so equip the plant that either oil or a gas such as propane may be supplied through a pipe 119 to the valve 104 and from the valve through a pipe 111 to the mixer 103.

Regardless of whether gas or oil is used in the operation of the plant, a gaseous mixture of hydrocarbon gas and steam is delivered through a pipe 112 to the valve 8 at the furnace. The flow of gas into the mixer 103 is controlled by an automatic regulator 113, the flow of oil in liquid form into the mixer 103 is controlled by an automatic regulator 114, and the flow of steam into the mixer 103 is controlled by the automatic regulator 115. Each of these regulators may be set manually to control the flow of a fluid therethrough within reasonable limits of, for example, within 5%, plus or minus, an established mean.

A satisfactory form of mixer is shown in Figs. XXV and XXVI. It consists of a body 120 in which is threaded a shell 121. Between the end of the shell 121 and the body 120 is a diaphragm member 122 having a constricted orifice 123, the diaphragm member 122 dividing the interior of the mixer into a steam chamber 124 and a mixing chamber 125. When gas is used through the pipe 111, it is mixed with steam delivered to the steam chamber 124 through the pipe 115 and delivered to the mixing chamber 125 through the orifice 123. A liquid hydrocarbon or oil is delivered to mixing chamber 125 through the pipe 110 whenever the valve 104 is turned to deliver oil.

If the suitable hydrocarbon is a gas at atmospheric pressure, saturated steam may be used as a diluent, but, if any substantial fraction of the hydrocarbon so used has a boiling point substantially above the temperature of saturated steam at ordinary boiler pressures, such pressures would not vaporize all such fractions and superheated steam must be used.

When operating on a liquid hydrocarbon delivered by the pipe **109**, the steam performs a double function. It furnishes the heat to vaporize the hydrocarbon and it acts as a diluent to reduce the partial pressure of the hydrocarbon in the in-gas delivered to the furnace through the valve **8** and thus reduces the temperature required to fully vaporize the liquid. It may also act to maintain the in-gas at a high temperature as it enters the reaction zone. However, the heat efficiency of superheaters of practical size is rather low and I prefer to use fuel in the furnaces rather than in the superheater.

I prefer to maintain a vacuum of about 15 inches of mercury in the furnace, but this vacuum may vary considerably, and still result in a substantial production of the desired gas or gases provided that the combined effect of vacuum and steam is sufficient to result in a low partial pressure of feed stock. The pressure found to be satisfactory is about 5 inches of mercury for a C_1 feed and proportionately less as the carbon is increased. For propane or other C_3 gases the pressure should be two inches, butane, 1½", etc. The steam should be sufficiently superheated to maintain it at least slightly superheated in the in-gas passing through the valve **8**. A higher superheat may result in a somewhat better economy, but a very high superheat may result in operational difficulties or a lower efficiency.

I claim as my invention:

1. A furnace adapted to form an off-gas containing a desired hydrocarbon by the pyrolysis of a suitable hydrocarbon, comprising:

a gas-tight metal shell;

a heat refractory lining in said shell;

two main regenerative masses separated by a central space and so placed as to leave an end space at each end of the furnace;

three auxiliary regenerative masses placed in said central space, all of the regenerative masses being so placed that passages through said masses provide open paths from one end of the furnace to the other end, said auxiliary masses being spaced apart and spaced from said main masses to divide said central space into four subspaces separated by said auxiliary masses;

four series of fuel feeding nozzles in said furnace, each series of nozzles feeding fuel into one of said subspaces;

valve means for feeding fuel through each of said nozzles, and adapted to feed fuel in substantially equal amounts through all of said nozzles, or in substantially equal amounts only to the two innermost subspaces, or in substantially equal amounts only to the two outermost subspaces, or in substantially equal amounts to the outermost of said subspaces and in reduced amounts to the innermost of said subspaces; and

air valve means for feeding air into each of said end spaces, said means being so placed and operated that air is fed into each end space whenever fuel is being fed into that end of said central space.

2. A furnace adapted to form an off-gas containing a desired hydrocarbon by the pyrolysis of a suitable hydrocarbon, including:

a gas-tight metal shell;

a heat refractory lining in said shell;

two main regenerative masses separated by a central space and so placed as to leave an end space at each end of the furnace;

first, second, and third auxiliary regenerative masses placed in said central space, all of said masses having

longitudinal passages therethrough to provide open paths from one end of the furnace to the other end, said auxiliary masses being spaced apart and spaced from said main masses;

a first nozzle means communicating with said central space between one of said main masses and said first auxiliary mass for feeding fuel thereto;

a second nozzle means communicating with said central space between said first and second auxiliary masses for feeding fuel thereto;

a third nozzle means communicating with said central space between said second and third auxiliary masses for feeding fuel thereto;

a fourth nozzle means communicating with said central space between said third auxiliary mass and the other of said main masses for feeding fuel thereto;

means for selectively feeding fuel through said nozzle means;

means for alternatively feeding air into said end spaces; and

means for selectively throttling the flow of fuel through said nozzle means to vary the temperature profile curve from end-to-end of the furnace.

3. A furnace adapted to form an off-gas containing a desired hydrocarbon by the pyrolysis of a suitable hydrocarbon, including:

a gas-tight metal shell;

a heat refractory lining in said shell;

two main regenerative masses separated by a central space and so placed as to leave an end space at each end of the furnace;

first, second, third, and fourth auxiliary masses placed in said central space, all of said masses having longitudinal passages therethrough to provide open paths from one end of the furnace to the other end, said auxiliary masses being spaced apart and spaced from said main masses;

a first nozzle means communicating with said central space between one of said main masses and said first auxiliary mass for feeding fuel thereto;

a second nozzle means communicating with said central space between said first and second auxiliary masses for feeding fuel thereto;

burner means communicating with said central space between said second and third auxiliary masses;

a third nozzle means communicating with said central space between said third and fourth auxiliary masses for feeding fuel thereto;

a fourth nozzle means communicating with said central space between said fourth auxiliary mass and the other of said main masses for feeding fuel thereto;

means for selectively feeding fuel through said nozzle means; means for selectively throttling the flow of fuel through said nozzle means to vary the temperature profile curve from end-to-end of the furnace;

means for feeding a heating mixture through said burner means; and

means for alternatively feeding air into said end spaces.

4. In a furnace installation for the pyrolysis of hydrocarbons, the combination of:

first and second regenerative furnaces, each having a gas-tight metal shell, a heat refractory lining in said shell, two main regenerative masses in said lining and separated by a central space and so placed as to leave first and second end spaces at the ends of the furnace, a central regenerative mass in said space and between said main masses, and series of fuel feeding nozzles in the furnace communicating with said central space;

first connecting means for alternatively connecting said source of in-gas with the first or second spaces of both of said furnaces;

second connecting means for alternatively connecting said source of air with the first or second end spaces of both of said furnaces;

third connecting means for alternatively connecting

said source of fuel with the central spaces of said furnaces;

fourth connecting means for alternatively connecting said point of gas storage with the first or second end spaces of both of said furnaces;

fifth connecting means for alternatively connecting said point of gas discharge with the first or second end spaces of both of said furnaces;

means for continuously feeding in-gas through said first connecting means, in a first step, to the second end space of said second furnace, then in a second step to the second end space of said first furnace, then in a third step to the first end space of said second furnace, and then in a fourth step to the first end space of said first furnace;

means for continuously drawing off cracked gas through said fourth connecting means to the point of gas storage, in said first step from the first end space of said second furnace, in said second step from the first end space of said first furnace, in said third step from the second end space of said second furnace, and in said fourth step from the second end space of said first furnace;

means for continuously feeding fuel through said third connecting means from said source of fuel, in said first

and third steps, to the central space of said first furnace, and in said second and fourth steps to the central space of said second furnace; and

means for continuously feeding air through said second connecting means from said source of air, in said first step to the first end space of said first furnace, in said second step to said second end space of said second furnace, in said third step to said second end space of said first furnace, and in said fourth step to said first end space of said second furnace.

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