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DEVICE AND PROCESS FOR CONVERTING HYDROCARBONS

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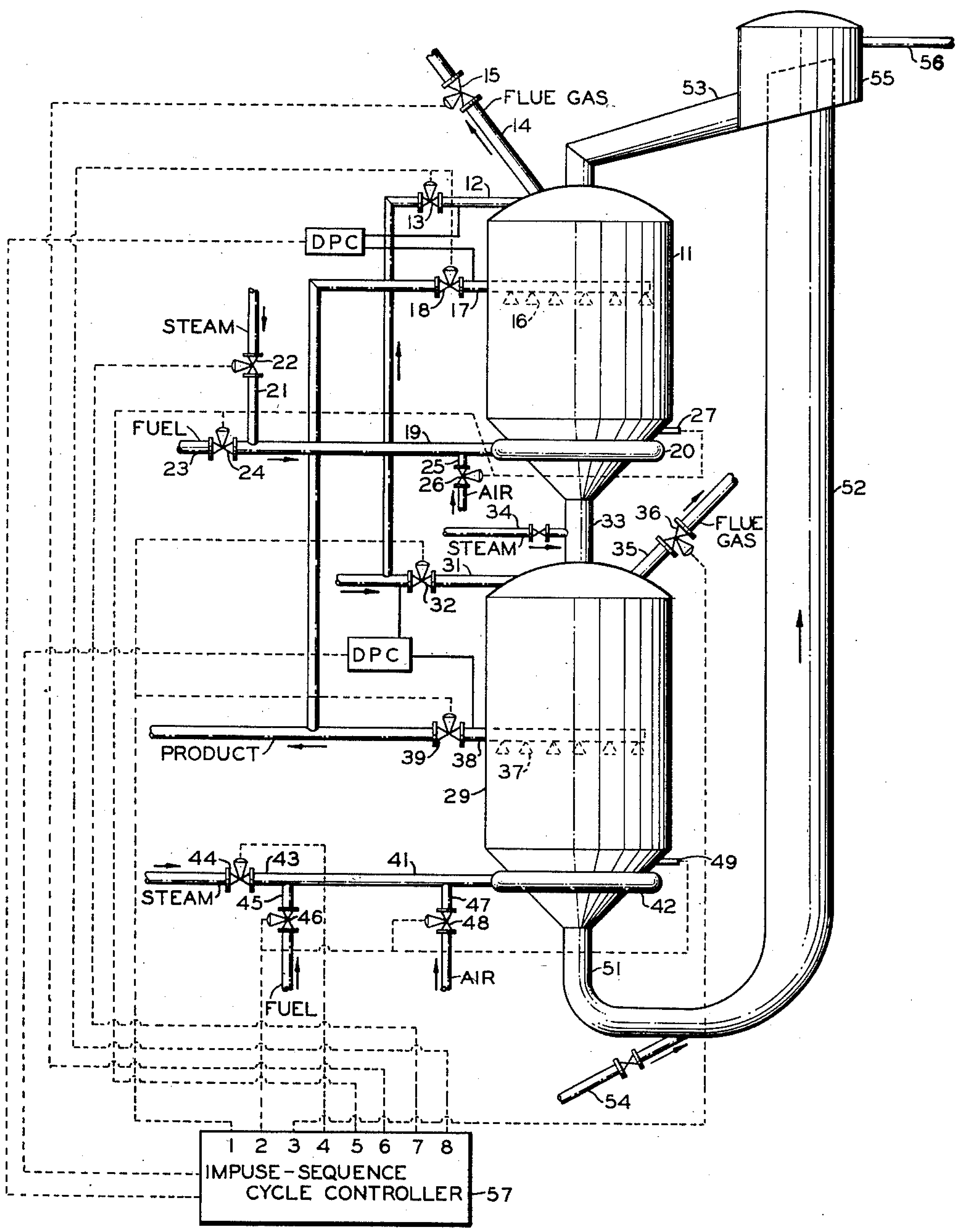

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DEVICE AND PROCESS FOR CONVERTING HYDROCARBONS

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1

This invention relates to the conversion of hydrocarbons. In one of its more specific aspects, it relates to a process for cracking hydrocarbon oils at high temperatures. In another of its more specific aspects, it relates to a semi-continuous process for converting hydrocarbon oils to lower boiling products. In another of its more specific aspects, it relates to an improved system for converting heavy residual oils to lower boiling products in a semi-continuous manner.

Heavy residual oils have long posed a considerable problem in the petroleum industry. Although the refining technique of the petroleum industry has improved greatly during the past several years, heavy residual oils have been of little or no value because of the great tendency of such materials to form and deposit coke, tar, and other carbonaceous materials in refining equipment. As the demand for petroleum products has has increased, that demand has placed a greater burden upon the available natural resources of the world and has focused attention more directly upon what heretofore had been deemed waste material. Heavy residual oils are very closely akin to waste materials and it is believed therefore that any process which aids in the utilization of such materials is of very great importance.

Many processes have been set forth in the petroleum art by which it has been proposed to convert heavy residual oils to provide normally lighter materials such as hydrogen, gasoline stocks, and other hydrocarbon products. As pointed out above, however, the tendency for such materials to form carbonaceous deposits has made such processes relatively uneconomical. Recent developments in petroleum conversion techniques have utilized pebble heater apparatus for converting heavy residual oils to lower boiling materials. Such improved techniques still, however, have inherent disadvantages. One of the main disadvantages of using pebble heater apparatus in the conversion of heavy residual oils as in the conversion of other hydrocarbon oils and lighter hydrocarbons is that during the conversion, a portion of the reaction products comes in contact with the reaction chamber or gaseous effluent outlet for a period of time sufficient to allow those materials to be converted to coke thereon. The coke lay-down develops to such an extent that pressure drop through the chamber becomes excessive. I have devised a process and a system whereby the disadvantages resulting from the tendency for products of such hydrocarbons to develop coke deposits

2

about the product outlet conduit in the reaction chamber are overcome by reason of the fact that I utilize an alternating semi-continuous process for the conversion of such materials. In this process the coke is burned from one chamber while heating particulate solid heat exchange material therein.

Broadly speaking, this invention comprises heating a bed of particulate solid heat exchange material within a first heat exchange chamber, passing that heated solid heat exchange material into a second heat exchange chamber in which it is caused to contact heavy residual oil or other hydrocarbon oil or hydrocarbons supplied thereto as a reactant material, raising the reactant material to reaction temperature by the direct heat exchange between the reactant material and the hot solid heat exchange material, and removing reaction products from the second heat exchange chamber. As the reaction proceeds within the second heat exchange chamber, tar vapors and hydrocarbon products contact the reaction chamber or product outlet until a portion thereof is converted to coke thereon. As coke builds up in that chamber so as to unduly increase the pressure drop therethrough, reactant materials are diverted from the second chamber, heating material is diverted from the first chamber, the first and second heat exchange chambers are purged with a purging gas, such as steam, and the second heat exchange chamber is converted to a heating chamber for heating the solid heat exchange material and the first heat exchange chamber is converted to a reaction chamber.

An object of this invention is to provide an improved method for converting hydrocarbons. Another object of the invention is to provide an improved system for converting hydrocarbons. Another object of the invention is to provide an alternating semi-continuous method for converting hydrocarbon oils in pebble heater apparatus. Another object of the invention is to provide a method for converting hydrocarbon oils at an increased rate. Another object of the invention is to overcome the problem of coke accumulation in pebble heater apparatus during conversion of hydrocarbon oils to normally lower boiling materials, such as hydrogen, aromatic distillates, and normally gaseous materials, such as ethylene, propylene, acetylene, and the like. Other and further objects and advantages will be apparent to those skilled in the art upon study of the accompanying disclosure and the drawing.

Solid heat exchange material which may be utilized in the pebble heater system of this invention is generally termed "pebbles." The term "pebbles" as used herein denotes any substantially solid material of flowable size and form which has sufficient strength to withstand mechanical pressures and the temperatures encountered within the pebble heater system. These pebbles must be of such structure that they can carry large amounts of heat from one chamber to another without rapid deterioration or substantial breakage. Pebbles which may be satisfactorily used in this hydrocarbon conversion system may be substantially spherical in shape and range from about one-eighth inch to about one inch in diameter. The pebbles are preferably of a size within the range of from one-eighth inch to five-eighths inch in diameter. Materials which may be used singly or in combination in the formation of such pebbles include among others alumina, silicon carbide, periclase, beryllia, mullite, nickel, cobalt, copper, iron, magnesia, and silica.

More complete understanding of the invention will be obtained upon reference to the schematic drawing which is a diagrammatic elevation of a pebble heater apparatus, together with a flow plan utilized in the automatic operation of this system.

Referring particularly to the device shown in the drawing, heat exchange chamber 11 is provided with a hydrocarbon feed inlet conduit 12 in its upper end portion having flow control valve 13 provided therein. Gaseous effluent outlet conduit 14, having flow control valve 15 provided therein, is also provided in the upper end portion of heat exchange chamber 11. Product collector system 16 is provided intermediate the ends of heat exchange chamber 11 and may be any conventional type of gaseous material collector system utilized in pebble heater apparatus and the like. Product outlet conduit 17, having flow control valve 18 provided therein, extends between product collector system 16 and a product disposal point, not shown. Inlet conduit 19 is connected to the lower portion of heat exchange chamber 11 and, preferably as header member 20, extends at least a portion of the way around the lower part of that chamber communicating with the interior of the chamber through the wall thereof. Connected to inlet conduit 19 is steam inlet conduit 21 having flow control valve 22 provided therein. Fuel inlet conduit 23, having flow control valve 24 provided therein is also connected to inlet conduit 19. Air inlet conduit 25, having flow control valve 26 provided therein, is also attached to inlet conduit 19. It should be obvious to those skilled in the art that considerable modification of this combination of inlets can be made without departing from the spirit or the scope of this disclosure. The combination of gaseous material inlets to form a single gaseous material inlet is, however, believed to be the most feasible method of operation of this chamber. Igniter means 27, which may be any conventional means for igniting a gaseous fuel material, such as a spark plug or the like, is provided so as to communicate with the interior of the lower portion of heat exchange chamber 11, preferably at a point adjacent gaseous material inlet header 20.

Heat exchange chamber 29 is provided in its upper end portion with a reactant material inlet conduit 31 having flow control valve 32 provided therein. Reactant material inlet conduit 12 and conduit 31 may be connected together as shown in the drawing or may extend separately from a reactant material supply source, not shown. Solid heat exchange material conduit 33 extends between the lower portion of heat exchange chamber 11 and the upper end portion of heat exchange chamber 29. Gaseous material inlet conduit 34 is provided for the introduction of an inert gas, such as steam, or some other hot gaseous material which is inert to the reaction, into solid heat exchange material conduit 33. Gaseous effluent outlet conduit 35 having flow control valve 36 provided therein, extends from the upper end portion of heat exchange chamber 29. Product collector 37, which is similar to collector system 16, is provided intermediate the ends of heat exchange chamber 29. Product outlet conduit 38, having flow control valve 39 provided therein, extends between product collector system 37 and a product disposal point, not shown. Product outlet conduits 17 and 38 are preferably connected, as shown in the drawing, but these conduits may in one modification of the invention extend as separate conduits to a product disposal point. Inlet conduit 41 is connected to the lower end portion of heat exchange chamber 29 and extends preferably as header member 42 around at least a part of the lower portion of chamber 29 and communicates with the interior thereof through its lower wall portion. Steam inlet conduit 43, having flow control valve 44 provided therein, fuel inlet conduit 45, having flow control valve 46 provided therein, and air inlet conduit 47, having flow control valve 48 provided therein, are connected to inlet conduit 41 in the same manner as are conduits 21, 23, and 25 connected to conduit 19. Igniter means 49, which is similar to igniter means 27, is provided in the lower portion of heat exchange chamber 29 for igniting a gaseous fuel material therein. Solid material outlet conduit 51 extends from the lower portion of heat exchange chamber 29 to the lower portion of elevator 52. Elevator 52 is connected at its upper end portion to solid material inlet conduit 53 which extends into the upper end portion of heat exchange chamber 11. In the specific showing of the drawing, elevator 52 is a gas lift-type elevator, entraining gas being introduced thereinto through inlet conduit 54. Separator 55 is provided at the upper end portion of elevator 52 and is provided with gaseous material outlet conduit 56 therein.

In the operation of this invention pebbles are introduced into the upper portion of heat exchange chamber 11 through inlet conduit 53 and form a flowing contiguous pebble mass therein. A gaseous fuel and air are introduced into the lower portion of heat exchange chamber 11 and burned in the lower portion of that chamber in contact with the pebbles gravitating through that chamber. The system may be modified by introducing a hot combustion gas directly in contact with the gravitating pebbles within chamber 11. The hot combustion gases introduced directly into chamber 11 are formed by burning fuel on the surface of the pebbles and pass upwardly through the gravitating mass of pebbles, heating those pebbles to a high temperature, the specific temperature depending upon the desired reaction products from the system. When hydrocarbon oils are converted to normally gaseous materials or high aromatic gasoline constituents, reaction temperatures between 1000° F. and 2500° F. are ordinarily utilized, preferably 1100° F. to 1600° F. For production of materials, such as acetylene, higher temperatures in the range of between 1800° F. and 2500° F. are required. The temperature of the pebbles within the heating chamber is preferably about 200° F. above the highest desired reaction temperature within the reaction chamber. The combustion gases are removed from chamber 11 through gaseous effluent outlet conduit 14.

Pebbles which have been heated to reaction temperature in heat exchange chamber 11 are gravitated through solid material conduit 33 into the upper portion of heat exchange chamber 29 and form a flowing contiguous pebble mass therein. Hydrocarbon oil is introduced through conduit 31 into the upper portion of chamber 29 and is distributed over the surface of the hot pebbles within that chamber. The hydrocarbon oil can be introduced over the surface of the pebbles at a point within solid material conduit 33. The hydrocarbon oil is raised to reaction temperature in its direct heat exchange with the hot pebbles and the reaction products are caused to flow concurrently with the pebbles in chamber 29 downwardly to a point intermediate the ends of that chamber where they are collected by product collector system 37 and are removed from chamber 29 by means of product outlet conduit 38. The product materials contact the product outlets for a sufficient period of time that a portion thereof is converted to coke on the outlet conduit. Pebbles which are cooled in the reaction of the hydrocarbon oil are gravitated from heat exchange chamber 29 through conduit 51 and are entrained by introduction of a gas introduced through conduit 54 into elevator 52. The pebbles are elevated through elevator 52 to separator 55 in which the pebbles and the entraining gas are separated, the entraining gas being removed therefrom through conduit 56. The pebbles are gravitated through conduit 53 into the upper portion of heat exchange chamber 11.

As the coke deposits within heat exchange chamber 29 begin to cause excessive pressure drop therein, valves 32 and 39 are closed as are valves 24 and 26. Valves 22, 36, and 44 are opened and heat exchange chambers 11 and 29 are purged with steam for a very few minutes. Generally one to two minutes are sufficient to purge the chambers. Valves 15, 22, and 44 are then closed and valves 13, 18, 46, and 48 are opened. Igniter means 49 ignites fuel which is introduced into the lower portion of chamber 29 and pebbles within chamber 29 are heated in a manner similar to that described in connection with the heating of pebbles within chamber 11. Coke which has been deposited upon the surface of the pebbles within the reaction chamber may, together with other coke formation in chamber 29, be utilized as a portion of the heating material in that chamber by controlling the introduction of an amount of air thereinto in excess of that required to support the fuel introduced into chamber 29. Hydrocarbon oil is introduced into the upper portion of heat exchange chamber 11 in the same manner as described above in connection with the operation of chamber 29. The system is operated in this manner until coke deposits within chamber 11 begin to cause excessive pressure drop therein, at which time appropriate valves are closed and other appropriate valves are opened so as to purge each of the chambers with steam. Chamber 11 is then placed onstream as the pebble heating chamber, and chamber 29 is once again placed onstream as

the reaction chamber. Products removed from chambers 11 and 29 are quenched in a conventional manner, not shown, at a point downstream of valves 18 and 39.

The operation of this system is conveniently adapted to automatic operation by utilizing a time cycle controller such as an impulse-sequence time-cycle controller, which may be purchased on the open market, to periodically control the appropriate valves and automatically change the operation of the individual chambers at given time intervals. The impulse-sequence time-cycle controller described in The Bristol Company bulletin C305, August 1948, is advantageously used in this invention. Impulse-sequence cycle controller 57 is adapted so that control 1 actuates valves 32 and 39 so as to shut off the flow of material through conduits 31 and 38 at a predetermined time. Control 3 opens valve 36 and control 5 closes valves 24 and 26. Control 7 opens valve 22 to allow steam to flow upwardly through chamber 11 so as to purge combustion gas therefrom. The steam and combustion gas are removed through conduit 14. Control 4 opens valve 44 so as to allow steam to flow upwardly through and purge chamber 29 and the steam and purged materials are removed through outlet conduit 35. At the end of a given period of time, ordinarily one to ten minutes being sufficient, preferably 1 to 2 minutes, control 4 closes valve 44, control 2 opens valves 46 and 48 and actuates igniter 49 to ignite the fuel introduced into the lower portion of chamber 29 through header member 62. Control 7 closes valve 22. Control 6 closes valve 15 and control 8 opens valves 13 and 18. Pebbles are thus heated within chamber 29 and are elevated to the upper portion of chamber 11 in which the hydrocarbon reactant materials are distributed over the surface thereof. The reaction of the hydrocarbon oil is carried on within chamber 11 as described above in connection with the operation of chamber 29. The resulting products are removed from that chamber through product collector system 16 and product outlet conduit 17. Coke deposits are desirably removed at the end of a predetermined period, preferably within the range of 3 to 8 hours. The amount of coke which is deposited in such a manner as to undesirably increase pressure drop through the system will depend upon the particular reactant material and the reaction conditions within the chamber.

Control 6 opens valve 15, control 7 opens valve 22, control 8 closes valves 13 and 18, control 2 closes valves 46 and 48, and control 4 opens valve 44. Each of the heat exchange chambers is purged with steam in this manner for a purging period, preferably of about one to 2 minutes. Impulse-sequence cycle controller 57 once again operates, causing control 7 to close valve 22, control 5 to open valves 24 and 26, and to actuate igniter means 27 to ignite the fuel introduced into heat exchange chamber 11 through header member 28. Control 4 closes valve 44, control 3 closes valve 36, and control 1 opens valves 32 and 39. The heating of pebbles within chamber 11 and reaction of reactant materials within chamber 29, and removal of resulting reaction products from chamber 29 through product outlet conduit 38 is similar to that described above. Operation of each cycle of this system is preferably within the range of from 3 to 8 hours depending upon the type of oil being converted. Longer periods of operation may be obtained by slight modification of the impulse-sequence time-cycle controller, however.

This system may be modified so as to operate in response to a pressure differential within the reaction chamber by adapting differential pressure controllers to actuate impulse-sequence time-cycle controller **57**. The impulse-sequence time-cycle controller can be set so as to operate up to the final minute of its cycle, at which time it will be cut out automatically according to adjustment. As the pressure differential within the reaction chamber rises to an undesirable limit, such as for example 5 p. s. i. g., the appropriate pressure differential controller will actuate impulse-sequence time-cycle controller **57** to cause that controller to once again go into operation causing appropriate valves to be closed and opened so as to purge each of the chambers with steam, and appropriate valves to then be opened and closed so as to alternate the heat exchange chambers as heating and reaction chambers. The impulse-sequence time-cycle controller then operates up to the last minute of its set cycle, at which time it once again is automatically cut off of operation until it is again set in operation by the operation of the appropriate differential pressure controller operating with the chamber currently being utilized as a reaction chamber.

Although this invention has been particularly described in connection with the conversion of hydrocarbon oils, particularly heavy residuum oil, this invention is also advantageously utilized in the conversion of gaseous hydrocarbons.

Many modifications of this invention will be apparent to those skilled in the art upon study of the accompanying disclosure and the drawing. It is believed that such modifications are clearly within the spirit and the scope of this disclosure.

I claim:

1. A semi-continuous process for converting hydrocarbons to lower boiling products which comprises heating pebbles to a temperature of at least 1200° F. in a first chamber of a pebble heater system by direct heat exchange with a hot heating gas; passing said hot pebbles through a second chamber of said pebble heater system; heating hydrocarbons to reaction temperature by direct contact with said hot pebbles in said second chamber; removing reaction products from said second chamber; returning pebbles from said second to said first chamber; purging said first and second chambers of hot heating gas, hydrocarbons and reaction products upon excessive increase of pressure drop through said second chamber; reversing operation of said pebble heater system by heating said pebbles to a temperature of at least 1200° F. by direct heat exchange with a hot heating gas in said second chamber; passing said hot pebbles through said first chamber; introducing hydrocarbons into direct heat exchange with said hot pebbles in said first chamber; heating said hydrocarbons to reaction temperature by said direct contact with said hot pebbles in said first chamber; removing resulting reaction products from said first chamber; returning pebbles from said first to said second chamber; purging said second and first chambers of hot heating gas, hydrocarbons and reaction products upon excessive increase of pressure drop through said first chamber; and similarly reversing operation of said pebble heater system as pressure drop through the chamber containing the hydrocarbon reaction becomes excessive.

2. A semi-continuous process for converting hydrocarbon oils to lower boiling products which comprises continuously and serially gravitating solid heat exchange material through a first heat exchange chamber and a second heat exchange chamber and recycling said solid heat exchange material to said first heat exchange chamber; heating said solid heat exchange material to a temperature in the range of between 1200° F. and 2700° F. in said first heat exchange chamber by direct heat exchange with hot gaseous heat exchange material; introducing hydrocarbon oil into the upper portion of said second heat exchange chamber in direct heat exchange with said hot solid heat exchange material therein, whereby said hydrocarbon oil is raised to reaction temperature; removing resulting reaction products from a point intermediate the ends of said second heat exchange chamber; discontinuing the flow of hot gaseous heat exchange material and hydrocarbon oil to said first and second chambers prior to the development of excessive pressure drop through said second chamber; purging said first and second chambers with a purge gas for a short period of time; heating said solid heat exchange material to a temperature within the range of between 1300° F. and 2700° F. and oxidizing any coke in said second heat exchange chamber by passing a hot gaseous heat exchange material together with an excess of oxygen therethrough; introducing hydrocarbon oil into the upper portion of said first heat exchange chamber; raising said hydrocarbon oil to reaction temperature by direct heat exchange between said oil and said hot solid heat exchange material from said second chamber; removing resulting reaction products from a point intermediate the ends of said first heat exchange chamber; discontinuing the flow of hot gaseous heat exchange material and hydrocarbon oil to said first and second chambers prior to the development of excessive pressure drop through said first chamber; purging said first and second heat exchange chambers with a purge gas for a short period of time; and similarly periodically reversing operating of said heat exchange chambers as heating and reaction chambers in said process as pressure drop through the chamber containing the hydrocarbon reaction becomes excessive.

3. A process of claim 2 wherein said solid heat exchange material is heated in each heat exchange chamber during its operation as a heating chamber to a temperature within the range of between 1300° F. and 1800° F.

4. A process of claim 2 wherein said solid heat exchange material is heated in each heat exchange chamber during its operation as a heating chamber to a temperature within the range of between 2000° F. and 2700° F.

5. A semi-continuous process for converting hydrocarbon oil to lower boiling products which comprises gravitating particulate solid heat exchange material through a first heat exchange zone in direct heat exchange with hot gaseous heat exchange material, whereby said solid material is heated to a temperature within the range of between 1200° F. and 2700° F.; gravitating said hot solid heat exchange material into the upper portion of a second heat exchange zone and downwardly therethrough; introducing hydrocarbon oil into the upper portion of said second heat exchange zone in direct heat exchange with said hot solid heat exchange material; converting at least a portion of said hydrocarbon oil to lower boiling

materials in said second heat exchange zone; withdrawing resulting reaction products from a point intermediate the ends of said second heat exchange zone; passing solid heat exchange material from the lower portion of said second heat exchange zone into the upper portion of said first heat exchange zone; stopping flow of said hot gaseous heat exchange material and hydrocarbon oil through said first and second heat exchange zones at the end of a period within the range of between 3 and 8 hours; passing steam upwardly through said first and second heat exchange zones for a period of between 1 and 10 minutes, whereby said first and second heat exchange zones are purged of said hot gaseous heat exchange material, said hydrocarbon oil and reaction products; stopping the flow of steam through said first and second heat exchange zones; passing hot gaseous heat exchange material and an excess of oxygen through said second heat exchange zone in direct heat exchange with said solid heat exchange material and removing any coke deposited in that chamber by oxidation thereof with said excess of oxygen, whereby said solid heat exchange material is raised to a temperature within the range of between 1200° F. and 2700° F.; introducing hydrocarbon oil into the upper portion of said first heat exchange zone in direct heat exchange with said hot solid heat exchange material therein, whereby said hydrocarbon oil is raised to reaction temperature; removing resulting reaction products from a point intermediate the ends of said first heat exchange zone; stopping the flow of hot gaseous heat exchange material and air and hydrocarbon oil to said second heat exchange zone and said first heat exchange zone at the end of a period within the range of 3 to 8 hours; passing steam upwardly through said first and second heat exchange zones so as to purge those zones of other gaseous materials; and similarly reversing operation of said heat exchange zones to alternate them as heating and reaction zones in said process.

6. The process of claim 5, wherein said hot gaseous heat exchange material is combustion gas formed by burning a fuel on the surface of said solid heat exchange material; and said fuel is automatically ignited upon its introduction into the heat exchange zone utilized for heating said solid heat exchange material.

7. An improved pebble heater system which comprises in combination a first closed upright elongated chamber; a pebble inlet conduit in the upper end of said first chamber; a first gaseous effluent conduit in the upper end portion of said first chamber; a first valve in said first gaseous effluent conduit; a first reactant material inlet conduit in the upper end portion of said first chamber; a second valve in said first reactant material inlet conduit; a first product collector intermediate the ends of said first chamber; a first product outlet connected to said first product collector means and extending from said first chamber; a third valve in said first product outlet conduit; a first fuel inlet conduit connected to the lower portion of said first chamber; a fourth valve in said first fuel inlet conduit; a first steam inlet conduit connected to the lower portion of said first chamber; a fifth valve in said first steam inlet conduit; a first air inlet conduit connected to the lower portion of said first chamber; a sixth valve in said first air inlet conduit; an igniter in the lower portion of said first chamber; a second closed upright elongated chamber below said first chamber; a pebble conduit extending between the lower portion of said first chamber and the upper end portion of said second chamber; a second gaseous effluent conduit in the upper end portion of said second chamber; a seventh valve in said second effluent conduit; a second reactant material inlet conduit in the upper end portion of said second chamber; an eighth valve in said second reactant material conduit; a second product collector intermediate the ends of said second chamber; a second product outlet conduit connected to said second product collector and extending from said second chamber; a ninth valve in said second product conduit; a second fuel conduit connected to the lower portion of said second chamber; a tenth valve in said second fuel conduit; a second steam conduit connected to the lower portion of said second chamber; an eleventh valve in said second steam conduit; a second air inlet conduit connected to the lower portion of said second chamber; a twelfth valve in said second air inlet conduit; a second igniter in the lower portion of said second chamber; a pebble outlet conduit in the lower end of said second chamber; an elevator connecting said pebble outlet conduit from said second chamber and said pebble inlet conduit in said first chamber; and an impulse-sequence cycle controller having a plurality of controls therein, a first control thereof operatively connected to said eighth and ninth valves, a second control thereof operatively connected to said tenth and twelfth valves and said second igniter, a third control thereof operatively connected to said seventh valve, a fourth control thereof operatively connected to said eleventh valve, a fifth control thereof operatively connected to said fourth and sixth valves and said first igniter, a seventh control thereof operatively connected to said fifth valve, and an eighth control operatively connected to said second and third valves.

8. An improved pebble heater system which comprises in combination a first closed upright elongated chamber; a pebble inlet conduit in the upper end of said first chamber; a first gaseous effluent conduit in the upper end portion of said first chamber; a first valve in said first gaseous effluent conduit; a first reactant material inlet conduit in the upper end portion of said first chamber; a second valve in said first reactant material inlet conduit; a first product collector intermediate the ends of said first chamber; a first product outlet conduit connected to said first product collector means and extending from said first chamber; a third valve in said first product outlet conduit; a first fuel inlet conduit connected to the lower portion of said first chamber; a fourth valve in said first fuel inlet conduit; a first steam inlet conduit connected to the lower portion of said first chamber; a fifth valve in said first steam inlet conduit; a first air inlet conduit connected to the lower portion of said first chamber; a sixth valve in said first air inlet conduit; an igniter in the lower portion of said first chamber; a second closed upright elongated chamber below said first chamber; a pebble conduit extending between the lower portion of said first chamber and the upper end portion of said second chamber; a second gaseous effluent conduit in the upper end portion of said second chamber; a seventh valve in said second effluent conduit; a second reactant material inlet conduit in the upper end portion of said second chamber; an eighth valve in said second reactant material conduit; a second product collector intermediate the ends of said second chamber; a second prod-

uct outlet conduit connected to said second product collector and extending from said second chamber; a ninth valve in said second product conduit; a second fuel conduit connected to the lower portion of said second chamber; a tenth valve in said second fuel conduit; a second steam conduit connected to the lower portion of said second chamber; an eleventh valve in said second steam conduit; a second air inlet conduit connected to the lower portion of said second chamber; a twelfth valve in said second air inlet conduit; a second igniter in the lower portion of said second chamber; a pebble outlet conduit in the lower end of said second chamber; an elevator connecting said pebble outlet conduit from said second chamber and said pebble inlet conduit in said first chamber; an impulse-sequence cycle controller having a plurality of controls therein, a first control thereof operatively connected to said eighth and ninth valves, a second control thereof operatively connected to said tenth and twelfth valves and said second igniter, a third control thereof operatively connected to said seventh valve, a fourth control thereof operatively connected to said eleventh valve, a fifth control

thereof operatively connected to said fourth and sixth valves and said first igniter, a seventh control thereof operatively connected to said fifth valve, an eighth control operatively connected to said second and third valves; a first differential pressure controller operatively connected to said first reactant material inlet conduit, said first product outlet conduit, and said impulse-sequence cycle controller; and a second differential pressure controller operatively connected to said second reactant material inlet conduit, said second product outlet conduit, and said impulse-sequence cycle controller.

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