Nov. 9, 1954

A. J. JOHNSON ET AL

2,694,037

METHOD AND APPARATUS FOR THE PRODUCTION OF SHALE OIL FROM OIL SHALE

Filed April 7, 1950

7 Sheets-Sheet 1

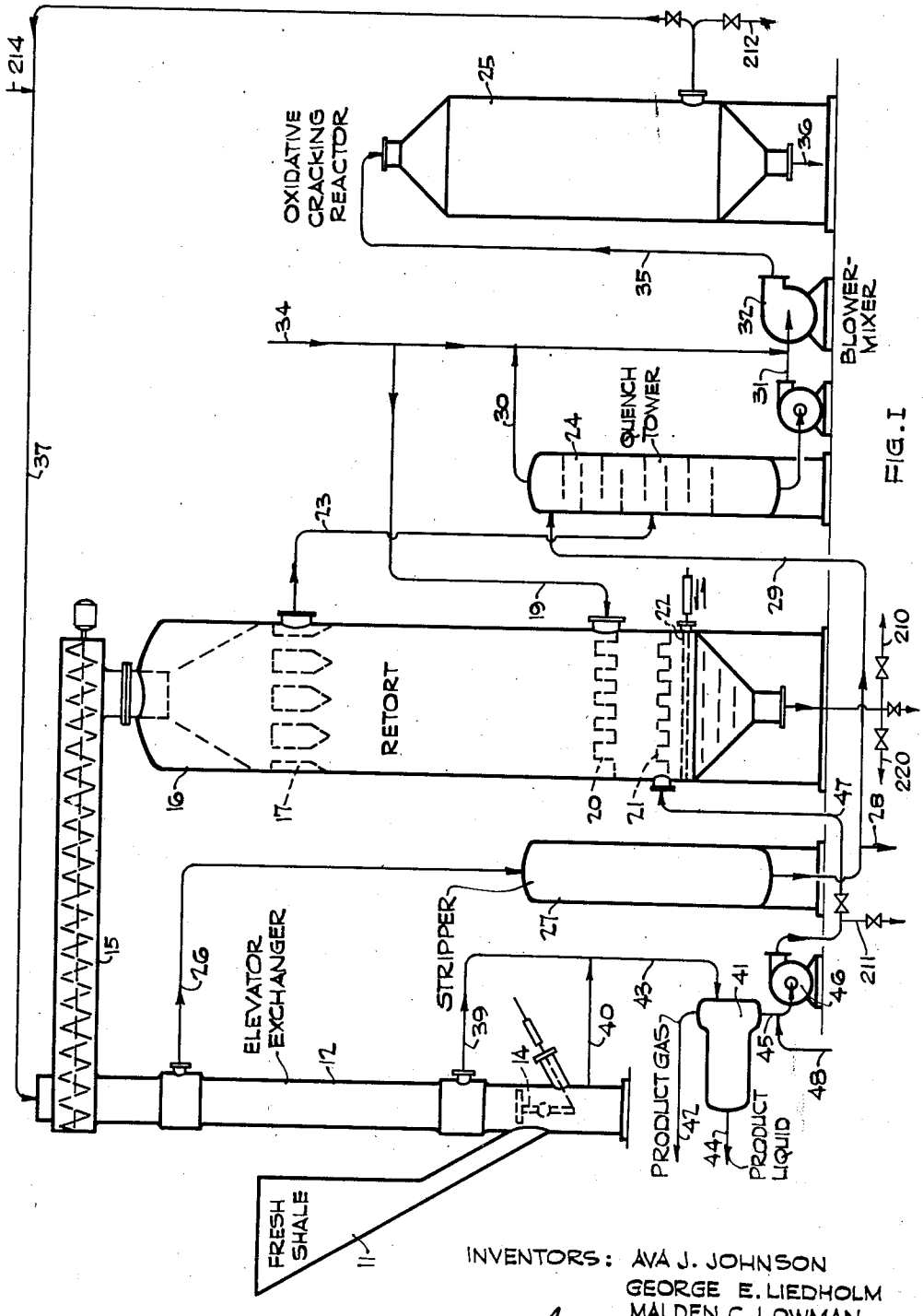

FIG. I

INVENTORS: AVA J. JOHNSON
GEORGE E. LIEDHOLM
MALDEN C. LOWMAN

BY James Todorovic
THEIR ATTORNEY

Nov. 9, 1954 A. J. JOHNSON ET AL 2,694,037

METHOD AND APPARATUS FOR THE PRODUCTION OF SHALE OIL FROM OIL SHALE

Filed April 7, 1950

7 Sheets-Sheet 2

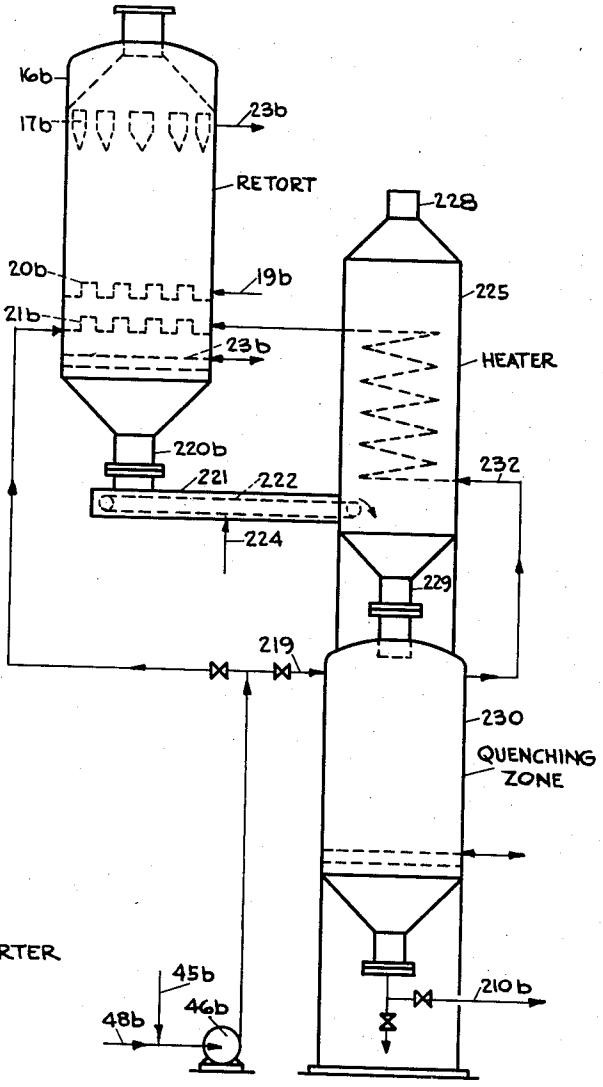

Fig. Ib

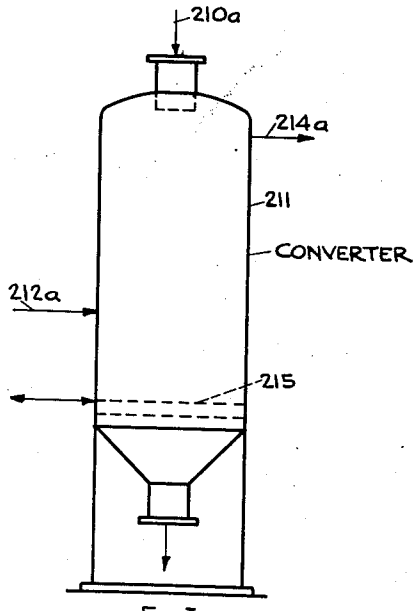

Fig. Ia

Inventors: Ava J. Johnson
George E. Liedholm
Malden C. Lowman

By: James Todorovic
Their Attorney

Nov. 9, 1954

A. J. JOHNSON ET AL

2,694,037

METHOD AND APPARATUS FOR THE PRODUCTION OF SHALE OIL FROM OIL SHALE

Filed April 7, 1950

7 Sheets-Sheet 3

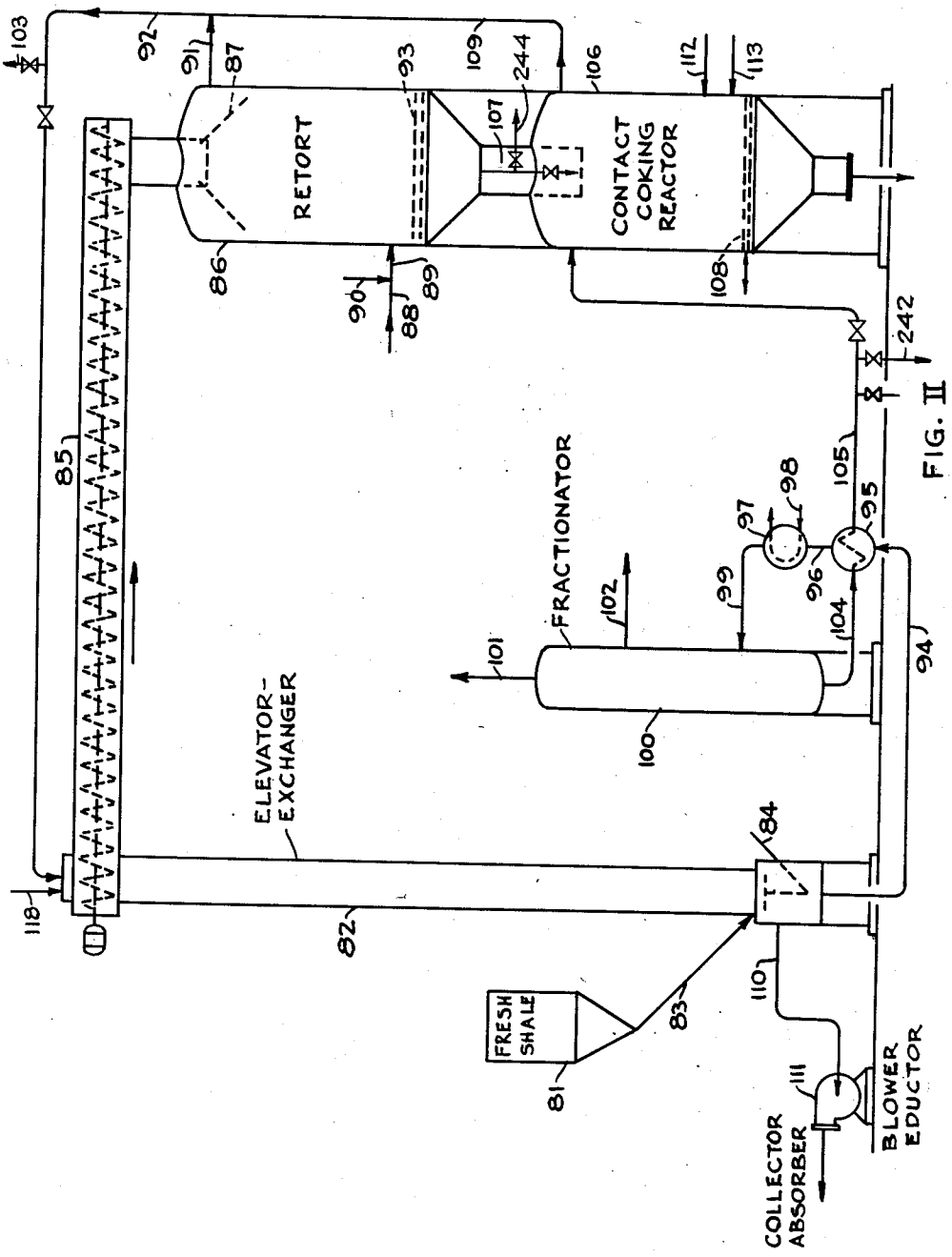

FIG. II

INVENTORS: AVA J. JOHNSON
GEORGE E. LIEDHOLM
MALDEN C. LOWMAN

BY: James Jodorowic
THEIR ATTORNEY

Nov. 9, 1954 A. J. JOHNSON ET AL 2,694,037

METHOD AND APPARATUS FOR THE PRODUCTION OF SHALE OIL FROM OIL SHALE

Filed April 7, 1950

7 Sheets-Sheet 4

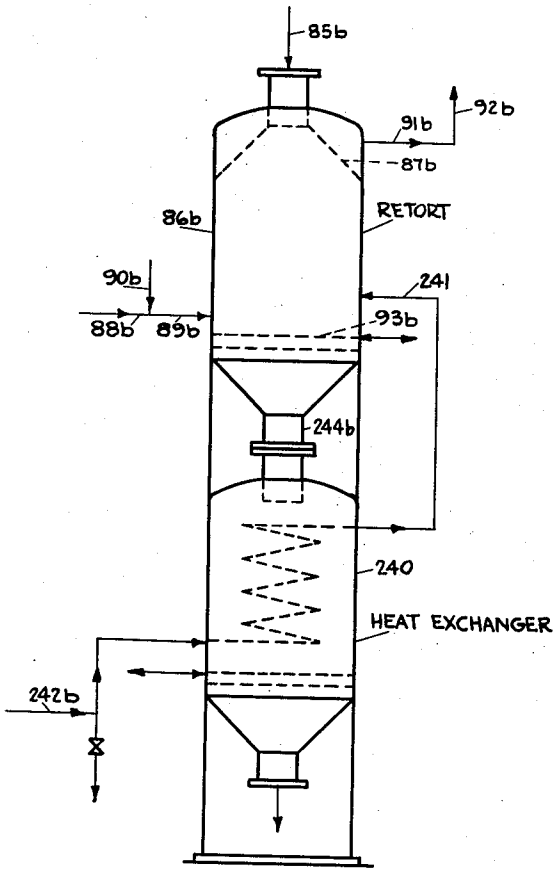

Fig. IIb

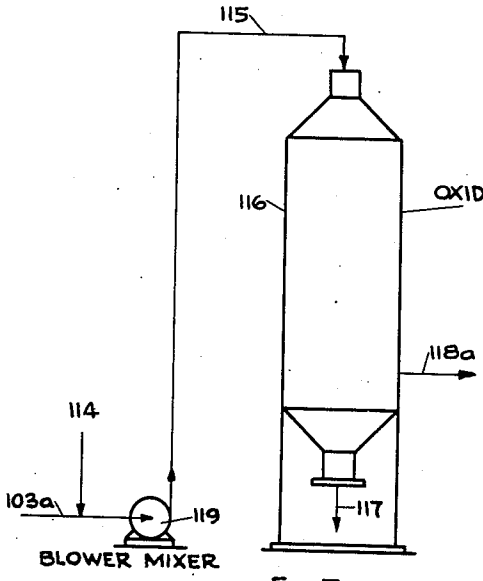

Fig. IIa

Inventors: Ava J. Johnson
George E. Liedholm
Malden C. Lowman

By: James J. Dorrie
Their Attorney

Nov. 9, 1954 A. J. JOHNSON ET AL 2,694,037

METHOD AND APPARATUS FOR THE PRODUCTION OF SHALE OIL FROM OIL SHALE

Filed April 7, 1950 7 Sheets-Sheet 5

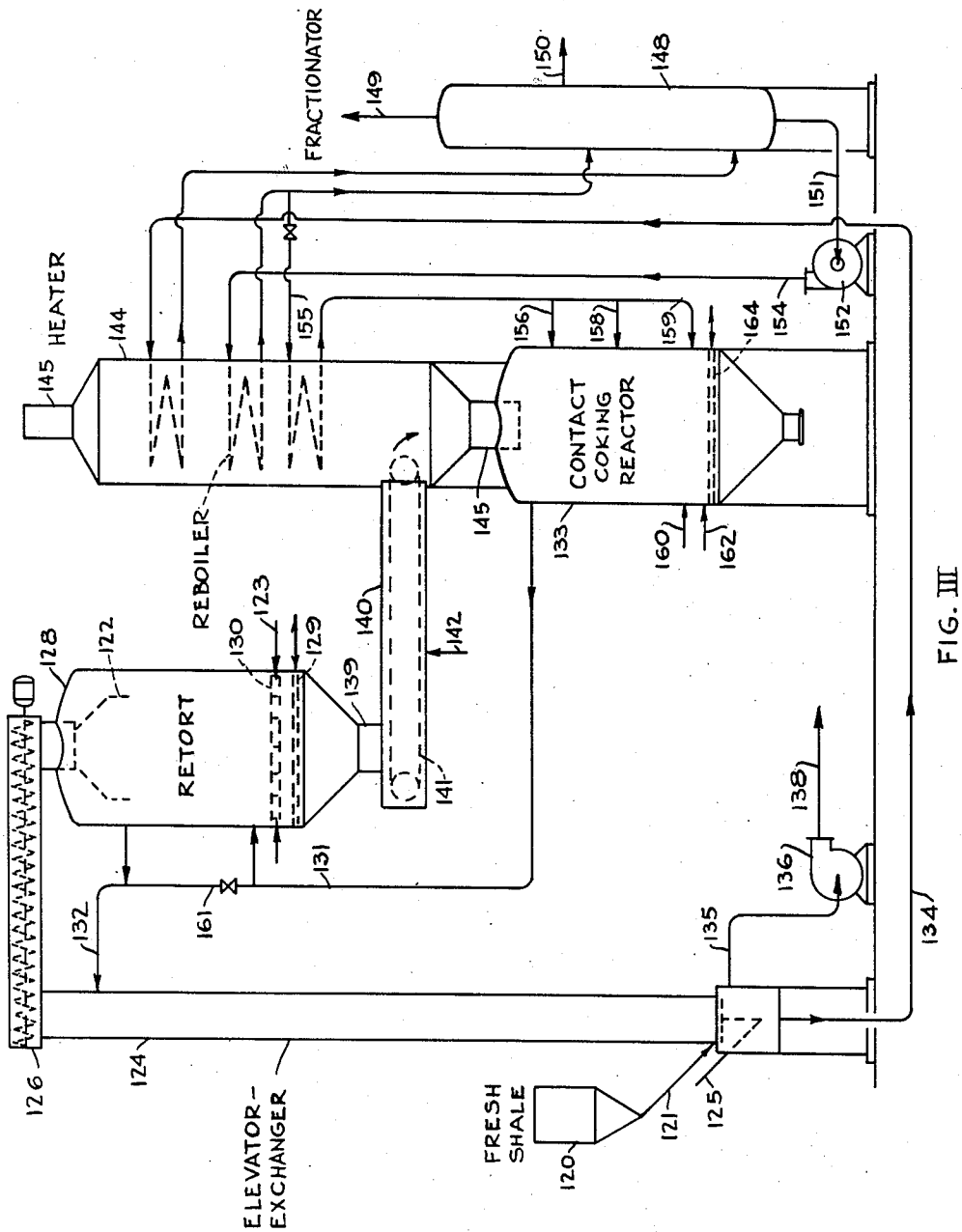

FIG. III

INVENTORS: AVA J. JOHNSON
GEORGE E. LIEDHOLM
MALDEN C. LOWMAN

BY: James Todorovic
THEIR ATTORNEY

Nov. 9, 1954 A. J. JOHNSON ET AL 2,694,037

METHOD AND APPARATUS FOR THE PRODUCTION OF SHALE OIL FROM OIL SHALE

Filed April 7, 1950 7 Sheets-Sheet 6

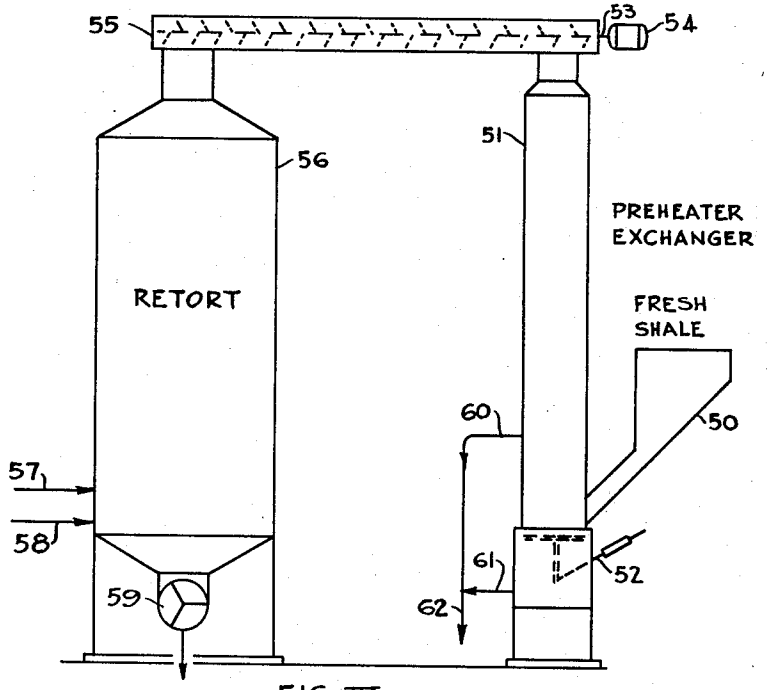

FIG. IV

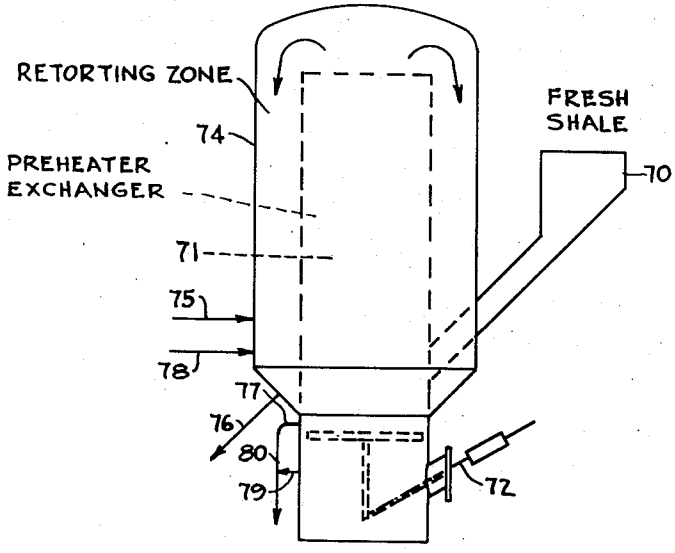

FIG. V

INVENTORS:
AVA J. JOHNSON
GEORGE E. LIEDHOLM
MALDEN C. LOWMAN

BY: James Todorovic
THEIR ATTORNEY

Nov. 9, 1954 A. J. JOHNSON ET AL 2,694,037

METHOD AND APPARATUS FOR THE PRODUCTION OF SHALE OIL FROM OIL SHALE

Filed April 7, 1950 7 Sheets-Sheet 7

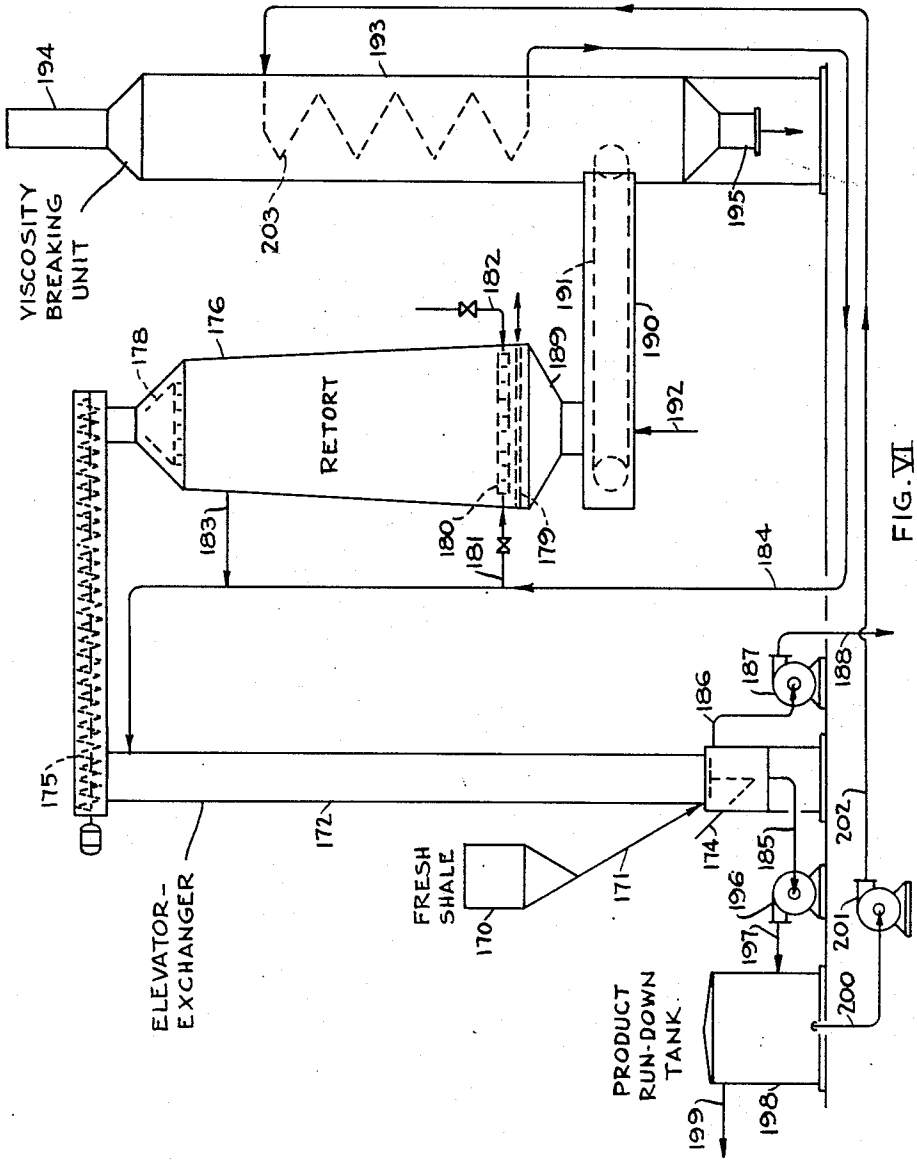

FIG. VI

INVENTORS: AVA J. JOHNSON
GEORGE E. LIEDHOLM
MALDEN C. LOWMAN

BY: James Todorovic
THEIR ATTORNEY

United States Patent Office 2,694,037 Patented Nov. 9, 1954

2,694,037

METHOD AND APPARATUS FOR THE PRODUCTION OF SHALE OIL FROM OIL SHALE

Ava J. Johnson, Oakland, George E. Liedholm, Berkeley, and Malden C. Lowman, San Rafael, Calif., assignors to Shell Development Company, San Francisco, Calif., a corporation of Delaware

Application April 7, 1950, Serial No. 154,482

11 Claims. (Cl. 196—56)

The present invention relates to the recovery of oil from oil shales. More particularly, the invention is concerned with the treatment of oil shales and other oil-bearing bituminous materials for the recovery of oil therefrom and the processing of the recovered oil.

It is well known in the art to recover oils from oil-bearing materials, particularly to recover oil from oil shales. In one of the methods presently receiving commercial consideration for the recovery of oil from oil-bearing material, oil shale is retorted in such a manner as to maintain a stationary zone of combustion near the top of an oil shale layer and at the same time moving fresh shale upwardly into this zone of combustion and drawing the products of combustion downward, countercurrently to the upward moving fresh shale, so as to preheat the latter and at the same time to drive off the petroleum oils and also to effect cooling and/or condensation of vaporized oil. In producing oil by this method it is necessary to introduce large quantities of air. As a result the product gases, containing the vaporized oils, are diluted with a large amount of inert nitrogen thereby decreasing the B. t. u. content of the product-combustion gas and also rendering the recovery of the C_3 and C_4 hydrocarbon gases therein very difficult. Various other retorting methods have also been suggested but so far none of the methods proposed have been entirely satisfactory.

The principal object of the present invention is to provide a method for recovering available petroleum oil from oil-bearing solid substances, and particularly, from oil shales. A more specific object of the invention is to recover petroleum oil from oil shale by the use of hot combustion gases arising from the combustion of previously extracted shale. Another object of the present invention is to provide a continuous method for recovering shale oil from oil shale and the like in a system generally operated at elevated temperatures in which the heat necessary to maintain the system in operation is obtained by burning materials within the system. Other objects of the invention will appear in the following more detailed description of the invention.

Now, a process has been discovered by which oil may be readily and efficiently recovered from oil-bearing materials, such as oil shales and other related materials. This process overcomes the inherent difficulties present in processes previously employed for the removal and recovery of oils from oil shales and the like and at the same time permits a maximum recovery of the oil in an efficient manner.

In accordance with the present invention, oil-bearing material, especially oil shales, are crushed, preheated by certain hot end-products of the process, as will be described, and then transferred to a retorting zone wherein the shale is passed downwardly countercurrently to hot gases so as to separate the oil from said oil-bearing material. At least a portion of the resulting oil in a vaporous state is then handled in a manner as to effect maximum heat economy consistent with efficient product recovery and quality.

A feature of one embodiment of the invention is to crack at least a portion of the recovered shale oil by oxidative cracking and to employ the heat thereby generated in the oil-recovery operation. In accordance with this embodiment of the invention crushed oil shale is countercurrently contacted with the gaseous product from a cracking reactor so as to preheat the oil shale, thereafter the oil shale is passed countercurrently to hot

gases within a retort so that shale oil is driven off from the oil shale and vaporized by these hot gases. Thereupon said vaporized shale oil is quenched by contact with a heavy shale oil fraction obtained by condensing and recovering a portion of the product vapors of said cracking reactor from said crushed oil shale and the resulting admixture in intimate mixture with oxygen is passed into said cracking reactor wherein oxidative cracking is carried out.

A feature of another embodiment of the invention is to crack at least a portion of the recovered shale oil by contact coking instead of oxidative cracking, in such a manner that hot spent shale provides the contact surface as well as a substantial portion of the heat required for coking. Thus, in accordance with this embodiment of the invention, crushed oil shale is countercurrently contacted with gaseous shale oil so as to preheat the oil shale and condense said shale oil, thereafter the oil shale is passed countercurrently to the hot gases within a retort so that shale oil is driven from the oil shale by these hot gases. Thereupon said shale oil is fractionated so as to produce light fractions which are drawn off as product and a heavy bottoms fraction which is then passed to a contact coking zone wherein it is contacted with hot spent shale and the heavy components of said bottoms fraction are thermally decomposed with the formation of a coke and lower molecular weight components. The shale oil vapors from the coking zone are commingled with the shale oil vapors from the retorting zone and the above-described fractionation step carried out again in such a manner as to maintain a continuous process.

The invention will be more fully understood from the following detailed description thereof made with reference to the drawings: Figure I of which is a diagrammatic representation of the process employing oxidative cracking; Figure I*a* of which is a diagrammatic representation of a modification of the method as illustrated in Figure I; Figure I*b* of which is a diagrammatic representation of a second modification of the method as illustrated in Figure I; Figure II of which is a diagrammatic representation of the process employing contact coking; Figure II*a* of which is a diagrammatic representation of a modification of the method as illustrated in Figure II; Figure II*b* of which is a diagrammatic representation of a second modfication of the method as illustrated in Figure II; Figure III of which is a diagrammatic representation of the process employing applicants' preferred method of contact coking; Figure IV of which is a diagrammatic representation of a method of preheating and retorting oil shale; Figure V of which is a diagrammatic representation of a modification of the method as illustrated by Figure IV and Figure VI of which is a diagrammatic representation of applicants' preferred method of preheating and retorting oil shale as illustrated by Figures IV and V.

Figure I shows diagrammatically an apparatus layout in which a preferred modification of the invention may be carried into effect.

Referring to Figure I, oil shale such as is found in vast quantities in the United States, particularly in Colorado, containing, for example, about 30 gallons of shale oil per ton, by Fischer assay test, after being crushed to an average size of about one inch is fed from fresh oil shale hopper **11** into an elevator-exchanger **12**. The elevator-exchanger is shown as a long, upright or inclined structure. Although it may have many forms, as will be well understood, it is preferably a bucket-type elevator with perforated bottoms in the buckets. An alternative would be to use a reciprocating feeder device such as is shown in the drawing at **14**. The fresh crushed oil shale is moved upward within the elevator-exchanger and transferred by suitable means **15**, such as a screw conveyor, to retort **16**. The retort may be a large upright vessel, lined with firebrick and containing distributing means **17** in the upper section near the top so as to evenly distribute the fresh incoming oil shale from the elevator-exchanger. In the lower section of the retort is located a zone of combustion maintained by a supply of oxygen from line **19** and introduced and distributed therein by

means 20. Close to this zone of combustion and directly beneath it is located means 21 for introducing and distributing the water used to cool the hot spent shale coming from the zone of combustion and thereby supply the steam required for the process and control of the volume percentage of oxygen in the zone of combustion. Still further, close to means 21 is means 22 which may be any of the many standard devices, such as shaking grates, to permit the cooled spent shale to be dropped from the retort. As is obvious from the above arrangement, the fresh shale, evenly distributed within the retort, moves downward uniformly under the force of gravity as the spent shale is ejected from the retort. The steam, formed when water introduced by means 21 to directly quench and cool the hot spent shale coming from the combustion zone, is superheated as it passes on up through the hot combustion zone; thus, the superheated steam and the hot combustion gases moving upwardly within the retort and countercurrently to the oil shale, serve to supply the heat necessary to drive off the oil from the oil shale.

The vaporized shale oil, swept along with the steam and combustion gases, leaves the retort by line 23 to a quench tower 24 wherein the vaporized shale oil is quenched and cooled in order to lower its temperature below the threshold temperature, above which rapid, excessive combustion would take place in subsequent oxidative cracking reactor 25. The quenching is accomplished by a liquid, unconverted, heavy oil fraction obtained from the elevator-exchanger as a side cut via line 26 and stripper 27 which is supplied with a suitable stripping agent such as steam, hot product gases, etc., to remove the light fractions from said heavy oil fractions from whence it is led by line 29 into the upper section of the quench tower. Valved line 28, which may lead to product separator 41, is a drawoff from line 29 so that the amount of heavy oil used for quenching may be varied. The cooled overhead vapor from the quench tower is led by line 30 and the liquid bottoms of the quench tower are led by line 31 to blower-mixer (eductor) 32 where a minor amount (from 1 to 20% by volume) of oxygen is added and mixed therewith, from line 34, and the mixture then blown through line 35 into the refractory-lined cracking reactor 25, an upright, unpacked reaction chamber wherein oxidative cracking occurs. Dry granulated coke which is produced and accumulates therein may be taken from the reactor by means of line 36. The gaseous products from the cracking reactor are then led by line 37 to the upper portion of the elevator-exchanger where they are cooled and condensed by the fresh incoming shale. This heat-exchange serves also to preheat the fresh shale.

The heavy unconverted oil used in the quench tower should preferably have an initial boiling point of at least about 200° C. It is readily seen, however, from the preceding description that the amount and properties of this quench oil are dependent upon the location from which it is withdrawn from the elevator-exchanger via line 26 and stripper 27, i. e., more oil and containing a greater proportion of lower boiling material (if desired) will be obtained if the quench oil is removed from a lower section of the elevator-exchanger than from a higher section. Also the temperature of the quench oil when removed from a higher section of the elevator-exchanger will be greater than the temperature of oil removed from the lower section. Thus, the amount of quenching oil required to bring its gaseous admixture with the gases emanating from the retort to a temperature below the threshold temperature desired for the oxidative cracking will vary according to the operating conditions of the process.

Furthermore, it may be desirable to employ a number of strippers, such as stripper 27, thereby effecting a separation of the shale oil being condensed within the elevator-exchanger into various fractions having the boiling point range desired and eliminating or greatly reducing the need for a fractionator to separate product-fractions from the liquid shale oil collected in product separator 41.

The condensed product from exchanger 12 is led by lines 39 and 40 to line 43 to separator 41, the uncondensed product gases being removed therefrom by line 42, the condensed liquid oil product being removed by line 44 and an aqueous layer being removed by line 45, from which it is delivered by means of pump 46 and line 47 to distributing means 21 in the lower section of the retort to supply the steam required for the process. It is pointed out that a condenser (not shown) supplied with a suitable coolant (shale oil product, water, air, etc.) may be placed between line 43 and separator 41 to recover uncondensed water and shale oil product emanating from the elevator-exchanger. Also make-up water, to replace any losses, may be added to the process by line 48 connecting with line 45.

It will be noted that in the above description of the process the oil shale moves evenly downwardly within the retort countercurrently to the hot combustion gases and superheated steam emanating from the zone of combustion. By permitting the oil shale to descend within the retort under the influence of gravity as the spent shale is removed an even solids flow is thereby achieved. This avoids the formation of stagnant layers of shale which tend to form around the walls of the retort causing channeling of the oil shale and gas flows which could occur in retorting processes wherein a zone of combustion in the upper section of the retorting zone is fed by an upward moving body of oil shale.

Oxygen of approximately 95% purity, such as may be readily obtained by the fractionation of air, is employed to maintain the zone of combustion in the lower section of the retort. It is realized that oxygen-enriched air or air may also be used but approximately pure oxygen is preferable. By employing oxygen it is possible to carry out an efficient combustion of the spent shale after the volatile hydrocarbon components have been driven off since the spent shale still contains from about 2% to about 5% by weight carbon. At the same time by controlling the amount of oxygen being admitted to the retort the extent and depth of the zone of combustion may also be more accurately controlled.

Another advantage gained by employing oxygen instead of air is that the light hydrocarbon gases, such as C_3 and C_4 hydrocarbons, driven off from the oil shale within the retort are not diluted with large quantities of nitrogen so as to render the separation of those light hydrocarbon gases difficult, impractical or uneconomical. Furthermore, since nitrogen is not present as a diluent, the heat content per unit of mass or volume of the gases emerging from the retort is greatly increased.

In the retort the water which is recycled and recovered from the products as an aqueous layer in the separator is employed not only as a means of quenching and cooling the hot spent shale from the zone of combustion to about 250° F. but also, because of its high specific heat, it is an efficient and excellent heating medium for use in the retorting section of the retort. In a sense, steam replaces nitrogen as a diluent if air instead of oxygen were employed in the retort but to the great advantage that steam may be readily separated from the light hydrocarbon gases. Also, because of the high latent heat of vaporization of water and the high specific heat of water vapor, the water serves to take up and/or supply a portion of the heat required for cooling and heating the shale. Furthermore, because of the high specific heat and latent heat of vaporization of water it is possible to maintain a relatively low total mass flow through the system as compared with a similar system not employing water while at the same time allowing for discharge of spent shale at a reasonably low temperature.

Another advantage gained by the use of steam is that the maximum temperatures in the retort may be controlled thereby avoiding overheating and calcination of the oil shale. This is advantageous because calcination of the carbonates in the fresh shale not only uses up a large amount of heat but also results in dilution of the hydrocarbon gases with carbon dioxide.

Still another advantage is that the use of steam not only results in a lower nitrogen content in the gaseous product but also offers the possibility of a simpler and more coordinated operation for the recovery of ammonia as a by-product of the shale oil.

For the reasons pointed out above, it is important to avoid excessive temperatures in the retorting section of the retort, i. e., that section wherein the volatile petroleum components are removed from the oil shale by the action of the hot gases and superheated steam. A suitable maximum temperature in the retorting zone is about 1200° F. Above this temperature calcination of the carbonates contained in the oil shale tends to become excessive. An operating temperature of about 900–1000°

F. in the retorting section with an oil shale residence time therein of about 2 hours is most suitable and preferable. However, as is obvious from the above discussion the operating conditions may be widely varied, dependent upon equipment, size of shale particles, richness of oil shale, etc.

The location of the quench tower or any other suitable liquid gas contacting device such as a mixing valve, etc., between the retort and the cracking reactor is most appropriate and advantageous. Not only are the hydrocarbon vapors, steam and combustion gases emerging from the retort cooled by direct contact with recycled heavy product obtained as a side cut from the elevator-exchanger in order to bring the feed to the oxidative cracking reactor below the threshold temperature above which rapid, excessive combustion would take place but it also serves as a particularly desirable and advantageous method and point for the introduction of recycle heavy oil to complete the cracking of this unconverted heavy oil. The threshold temperature below which it is desirable to cool the hydrocarbon vapors before oxidative cracking is in the neighborhood of 750° F.

Circulation of the gases through the process may be suitably obtained by means of a blower-mixer. The blower-mixer serves not only to educt the gases from the retort through the quench tower and then to blow them into the cracking reactor wherein the oxidative cracking is effected, but it also serves as an effective mixing device at the point of introduction of the oxygen into the feed for the reactor. An intimate and uniform feed mixture is necessary for successful and efficient operation of the oxidative cracking step carried out in the cracking reactor. The operating temperature of the cracking reactor should be carefully controlled since too high a temperature would cause excessive oxidation, resulting in low product yield and excessive formation of coke. It is preferred to operate the cracking reactor at a temperature in the range 650–1000° F., preferably about 950° F.

The oxidative cracking process is used to great advantage in this process since it serves to reduce the heating and the cooling requirements of the process. The latter is especially important because of the isolated location of oil-shale deposits away from large supplies of water. In addition, by utilizing the oxidative cracking process in the above-described manner, it is possible to use some of the heat of combustion in the cracking operation by heat-exchange with the fresh incoming shale to reduce the oxygen requirements in the retort.

Another advantage of using the oxidative cracking process is that it appears to be a convenient method to effect desulfurization. Since removal of sulfur is one of the many problems met in the refining of crude shale oil, the application of the oxidative cracking process to the crude shale oil is, therefore, particularly advantageous.

Still another feature of the above-described process is that in order to eliminate the presence of aldehydes, ketones, alcohols, and other oxygenated organic compounds which would occur in the liquid hydrocarbon product as a result of the oxidative cracking, since for certain purposes their presence therein would be undesirable, it is probable that by conducting the gaseous product coming from the cracking reactor over or through a bed of spent shale that the oxygenated organic compounds may be converted to the corresponding olefins. This feature of the invention is illustrated in Figure I*a* which represents, schematically, a converter which can be used in conjunction with the system shown in Figure I. Referring to Figures I and I*a* spent shale from retort **16** is conducted, e. g., by a suitable conveyor, through line **210** to converter **211**. The gaseous product from oxidative cracking reactor **25** is passed through line **212** to converter **211** wherein it is contacted with incoming spent shale. The gaseous product from the converter is discharged through line **214** into line **37** through which they are led to the upper portion of the elevator-exchanger where they are cooled and condensed by the fresh incoming shale. This heat exchange serves to preheat the fresh shale. Spent shale is discharged from the converter by suitable means **215**, e. g., shaking grates. Obviously, since the spent shale is to be discarded anyway, it is possible to carry out this treating step without a regeneration cycle, simply discarding the used spent shale at whatever rate is necessary to maintain a reasonable activity. It is contemplated that the activity of the spent shale used to convert these oxygenated organic compounds may be greatly increased by applying thereto mineral acids, such as oxy-mineral acids, such as sulfuric or phosphoric acids or mixtures of the same onto the incoming spent shale to the converter.

Another feature of the above-described process employing oxidative cracking is that the oxygen consumption in the retort can be reduced by burning some of the carbon still present on the spent shale with air in a separate zone below the zone of combustion but above the point of introduction of water. This can be done since not all the available carbon present in the oil shale is burned with oxygen. Steam can be generated by introducing water directly on the spent shale in a second separate section, and can be superheated by passage through an external heat-exchanger in indirect heat-exchange relationship with the hot combustion gases issuing from the first separate zone. This feature of the invention is illustrated in Figure I*b* which represents, schematically, by apparatus for carrying out this particular feature of the process shown in Figure I. Referring to Figures I and I*b*, hot spent shale, still containing appreciable amounts of carbon and other combustible materials, is dropped from retort **16** by shaking grates and is delivered by suitable means **220** to a burning or combustion zone **221**, for example, a furnace, which is equipped with a suitable device **222**, such as an endless chain grate, for the combustion therein of residual combustibles on the shale. The furnace is supplied with air by line **224** to maintain a zone of combustion therein. The hot gaseous products of combustion issuing from the furnace pass upwardly through heat-exchange zone **225** and are then dissipated into the atmosphere by stack **228** which is connected to the heat exchange zone. The hot solid products of combustion (shale ash) are discharged by the endless chain grate and conveyed by means **229** to the quenching zone **230**. The hot shale ash is contacted directly with water, which is delivered to the quenching zone by means of pump **46** and line **219**, whereby the hot shale ash is cooled and steam is generated. The resulting steam is then conducted by line **232** through heat-exchange zone **225**, wherein it is superheated by indirect contact with the hot combustion gases from furnace **221**, and is then delivered to distributing means **22** in the retort. The superheated steam together with the hot combustion gases from the zone of combustion in the lower section of the retort supply the heat necessary for driving off the shale oil from the oil shale.

Another feature of the invention is that the preheating and retorting steps may be carried out in combination with a contact coking step wherein hot spent shale from the retorting zone provides the contact surface as well as a substantial portion of the heat necessary to accomplish the coking reaction. This feature of the invention is of particular interest since experience has shown that coking, particularly of the heavier fractions of crude shale oil, is especially effective as an initial step in the refining of shale oil into products meeting present commercial specifications. This above-described feature of the invention is illustrated by Figure II which schematically shows an apparatus adapted to carry out this particular process.

Referring now to Figure II, fresh crushed oil shale such as is found in vast quantities in the United States, particularly in Colorado, containing, for example, about 30 gallons of shale oil per ton by Fischer assay test, after being crushed to an average size of about one inch is fed from fresh oil shale hopper **81** by means **83** into an elevator-exchanger **82**. As in Figure I, the elevator-exchanger is shown as a long, upright or inclined structure. Although it may have many forms it is preferably a bucket-type elevator with perforated bottoms in the buckets. An alternative would be to use a reciprocating feeder device as shown in the drawing at **84**. The fresh crushed oil shale is moved upward within the elevator-exchanger and transferred by suitable means **85**, such as a screw conveyor, to retort **86**. The retort may be a large upright vessel lined with firebrick and containing distributing means **87** in the upper section near the top so as to evenly distribute the fresh incoming oil shale within the retort. In the lower section of the retort is located a zone of combustion maintained by a supply of oxygen from line **88** and introduced into the combus-

tion zone by line 89. Steam from line 90 is also introduced into the combustion zone by line 89 in order to control the volume percentage of oxygen, thereby regulating the extent of the combustion zone and the temperature of the retorting section above the combustion zone. At the bottom of the retort is located suitable means 93, such as shaking grates which permit hot spent shale to drop from the combustion zone.

Thus, the hot combustion gases and the superheated steam from the combustion zone of the retort move upwardly through and countercurrently contact the downward moving mass of fresh oil shale within the retort and supply the heat necessary to drive off the shale oil from the oil shale.

The vaporized shale oil, swept along with the steam and combustion gases, leaves the retort by line 91 and moves along line 92 which leads to the top section of the elevator-exchanger wherein the vaporized shale oil and combustion gases contact the incoming fresh oil shale in direct countercurrent heat exchange, thereby preheating the fresh oil shale while at the same time the vaporized shale oil is condensed upon the oil shale. The liquefied shale oil thereupon flows downward to the bottom section of the elevator-exchanger where it is drawn off by means of line 94 and passed through heat exchanger 95. The shale oil leaves heat exchanger 95 by line 96 and then passes through heater 97 which is supplied with suitable heating means 98 and then along line 99 into fractionator 100. Therein the shale oil may be fractionated into three fractions, a liquid fraction with an end boiling point up to about 400° F. which is drawn off as a product by line 101, a medium fraction with an end boiling point of up to about 600° F., which is drawn off as a product by line 102 and a high-boiling oil (tarry) bottoms fraction which is drawn off by line 104, and which then passes through heat exchanger 95 so as to preheat the shale oil feed for the fractionator.

It is, of course, realized that it may not be desirable to take off two product streams from the fractionator as described above. Thus, it is possible, and at times preferable, to take off all the shale oil product overhead by line 101, eliminating a side-cut medium boiling fraction, and to draw off a bottoms fraction in sufficient quantity via line 104 for injection into the contact coking reactor.

From heat exchanger 95 the bottoms shale oil fraction is conducted by line 105 into contact coking reactor 106 at a point or points determined by the contact time desired and/or the operating conditions.

Reactor 106 is an upright reaction chamber wherein contact coking of the high-boiling, heavy bottoms fraction from fractionator 100 is accomplished. The reactor contains a mass of hot spent shale, supplied by means 107 as the shaking grate 93 permits the hot spent shale to drop from retort 86. The hot spent shale has a sufficiently high temperature, in the neighborhood of 1200° F., to coke the high molecular weight components of the heavy bottoms fraction from the fractionator. Reactor 106 operates in the following manner. A mass of hot spent shale, almost completely filling the reactor, is maintained therein at a high temperature (about 1000 to 1200° F.) by the combustion of the carbon on the spent shale with oxygen, air or an oxygen enriched gas introduced into the coking reactor by line 112. In general the heat required to maintain the spent shale at coking temperature may be supplied by any suitable and convenient method. The mass of hot spent shale within the reactor is contacted therein with the heavy bottoms fraction from the fractionator and introduced into the reactor via line 105. The temperature of this heavy shale oil fraction is rapidly increased as it contacts the hot spent shale and percolates down through the hot spent shale and as a result the shale oil is thermally decomposed with the resultant formation of some coke and lower molecular weight hydrocarbons. It should be noted that the contact coking carried out within reactor 100 is not equivalent to or similar to catalytic cracking. In catalytic cracking the cracking temperature is kept low in order to maintain a high catalytic activity of the catalyst employed. Furthermore, the oil fraction to be cracked is selected so that very little or no coke is formed upon cracking since coke formation is undesirable because it considerably reduces catalyst activity and life.

In accordance with the invention, however, the contact coking is carried out at a relatively high temperature, about 1000 to 1200° F., preferably 1000° F. Contact coking has been found to be a satisfactory method of treating a heavy shale oil fraction (such as the bottoms fraction of fractionator 100) to convert the same into a usable and less troublesome product. It is realized that in case the quantity of heavy bottoms product from the fractionator is insufficient to make up the required amount of recycle oil to the reactor which is necessary so as to provide the heat required to preheat the incoming fresh oil shale, it may be desirable to add to the heavy bottoms feed for the coking reactor a gas oil fraction from the fractionator, this may be achieved by taking off from the fractionator a product containing proportionally less high boiling components.

The hot spent shale, after being stripped of possible shale oil values by steam introduced into the bottom section of the reactor by line 113, is continuously discharged at a temperature of about 500° F. from the reactor by suitable means 108, such as shaking grates. The discharged spent shale still containing residual carbon as well as some coke deposited thereon as a result of contact coking the heavy shale oil fraction, may be used as fuel to supply power, steam and heat requirements of the plant carrying out the above-described process.

The heavy shale oil fraction decomposed and vaporized by contact with the hot spent shale leaves the upper section of the reactor by line 109 which is connected to line 92 wherein it is commingled with the vaporized shale oil from retort 86. This mixture of shale oil vapors is then treated according to the above-described method, maintaining a continuous process by the constant supply of fresh crushed shale and the constant removal of spent shale, fractionated shale oil and non-condensed vapors which are withdrawn from the lower section of the elevator-exchanger by line 110 to blower-eductor 111 which passes them to suitable absorbing and collecting means for the recovery, separation and purification of the valuable components thereof, e. g., ammonia, light hydrocarbon gases, etc.

Illustrative of the operating conditions and the material and heat requirements per ton of oil shale of a method of retorting oil shale according to a process of the invention, such as is represented by Figure II, the following data are presented below. It should be noted that heat and material requirements will vary over rather wide limits depending upon operating conditions such as, time and temperature of retorting, and contact coking, shale oil content of the oil shale retorted, whether oxygen or an oxygen enriched gas is employed to sustain combustion, etc.

Shale oil content per ton of oil shale (Fischer assay test).	30 gals.
Retorting temperature	900° F.
Combustion zone temperature of retort	1200° F.
Contact coking temperature	1000° F.
Oxygen required in retorting	300 s. c. f.
Temperature of gases from retort	900° F.
Heat required to raise oil shale from 60° F. to 900° F.	550,000 B. t. u.
Shale oil recovered as product	27 gals.
Heat delivered to oil shale by retort products.	122,000 B. t. u.
Temperature of recycled heavy oil to coking reactor.	550° F.
Temperature of gases from coking reactor.	1000° F.
Recycled heavy fraction to coking reactor.	85 gals.
Heat delivered to oil shale by coked, recycled heavy oil fraction and steam.	428,000 B. t. u.
Temperature of spent shale from coking reactor.	500° F.
Stripping steam required for coking reactor.	Approximately 15 lbs.
Oxygen required in coking	400 s. c. f.

As is seen from the foregoing description the process is similar to the shale oil recovery process described with reference to Figure I, wherein shale oil after recovery from oil shale is subjected to oxidative cracking. The points of similarity between the shale oil recovery processes as exemplified by Figures I and II are as follows: Both processes employ direct countercurrent heat exchange in the elevator-exchanger and retorting sections

of the processes and in both processes the fresh oil shale flows evenly downward under the influence of gravity countercurrently to the hot combustion gases. Both processes preferably employ oxygen of approximately 95% purity to maintain the zone of combustion in the lower section of the retort. It is also possible to substitute air or an oxygen-enriched gas for the 95% oxygen and/or steam in both processes but with the resultant disadvantage of thereby causing the recovered light hydrocarbon product gases to have a lower B. t. u. content and to be separated with difficulty. Both processes employ a cracking process to convert the high molecular weight shale oil components into lower molecular weight components. Both processes achieve heat economy and efficiency by utilizing the heat produced within the process as the source of heat for the recovery and cracking operations and both processes employ a heat exchange medium which carries a considerable amount of the heat required to maintain the process. Thus, in the process according to Figure I this heat exchange medium is water which is recycled in the process, absorbing heat from the retorting and oxidative cracking step and releasing heat to the incoming fresh oil shale within the elevator exchanger, whereas, in the above-described process according to Figure II, the heat exchange medium is a heavy shale oil fraction which is recovered by the fractionation of the shale oil from the elevator-exchanger, passed to the coking reactor, and which, after admixture with the vaporized shale oil from the retort, is passed to the elevator-exchanger where it releases its heat to the incoming fresh oil shale and is liquefied. The liquefied shale oil from the elevator-exchanger is then fractionated and the heavy bottoms fraction returned in the above-described manner to the contact coking reactor, etc.

In view of the above-indicated similarities of these two processes of the invention, it is obvious that there are possible many modifications, substitutions, combinations and variations embodying various features of these two processes. Thus it is possible, referring now to Figure II, to subject the gaseous mixture in line **92** coming from retort **86** and contact coking reactor **106** to oxidative cracking such as is carried out in the process embodied by Figure I, before passing the gaseous mixture to the elevator-exchanger since, as pointed out with reference to Figure I, oxidative cracking appears to be an excellent desulfurization process. This modification is shown in Figure II*a* which represents, schematically an oxidative cracking reactor which can be used in conjunction with the system shown in Figure II. Referring now to Figures II and II*a* the gaseous mixture in line **92** is passed through line **103** to blower-mixer **119**, where it is mixed with a minor amount (from 1 to 20% by volume) of oxygen, supplied by means of line **114**, and the resulting mixture is then blown through line **115** into the refractory-lined cracking reactor **116**, wherein oxidative cracking occurs. Dry granulated coke which is produced and accumulates therein may be taken from the reactor by means of line **117**. The gaseous products from the cracking reactor are then led by line **118** to the upper portion of the elevator-exchanger. Furthermore, elevator-exchanger **82** may be equipped with strippers in a similar manner and for the same purpose described with reference to Figure I, thereby eliminating the need for fractionator **100** while at the same time supplying a heavy oil fraction for the coking reactor.

Also in this modification it may be advantageous to subject the gases after oxidative cracking to the action of hot spent shale (obtained by the burning of the coke and residual carbon of the spent shale from reactor **106**) in order to convert any oxygenated organic compounds therein to their corresponding olefins in the manner set forth and described with reference to the process of Figure I.

Furthermore, referring now to Figure I it is possible to inject the quenching oil from line **29** into the hot shale of retort **16** above the combustion zone so as to subject the oil to thermal cracking and at the same time thereby eliminating the quenching and oxidative cracking steps of the process of Figure I and to a certain extent changing the process represented by Figure I to a process similar to that represented by Figure II except that contact coking reactor **106** is eliminated and thermal cracking instead of contact coking is employed.

Other possible variations and combinations of the processes set forth by Figures I and II are as follows: the process represented by Figure II may be modified by the elimination of contact coking reactor **106** and thermal cracking of the heavy shale oil fraction from line **105** may be carried out in that section of the retort above the combustion zone. The heavy shale oil fraction may be preheated by indirect heat exchange with the hot spent shale from the retort. This feature of the invention is illustrated in Figure II*b* which represents, schematically an apparatus which can be substituted for the contact coking reactor shown in Figure II. Referring to Figures II and II*b*, hot spent shale from retort **86** is delivered by means **244** to a heat-exchanger **240**. The heavy shale oil fraction from line **242** is conducted through the heat-exchanger in indirect heat exchange relationship with the hot spent shale therein, and is then delivered by means of line **241** into the retort at a point above the zone of combustion therein.

Also, still with reference to the process of Figure II it is possible to eliminate fractionator **100** and substitute in place thereof separation devices such as separator **41** and separating means **27** employed in the process of Figure I to affect fractionation of the shale oil. Similarly, with reference now to Figure I, it is possible to eliminate separator **41** and separating device (stripper) **27** and to substitute in place thereof fractionator **100** such as is shown in Figure II to accomplish the same purpose. Wherever in the above processes an elevator-exchanger and a retort are used in combination, as in Figures I and II, it is also possible and oftentimes advantageous to employ the elevator-exchanger and retort combinations shown in Figures IV and V. Many other modifications and combinations of the above processes are possible as will be evident to one skilled in the art.

Still another feature of the invention, which feature is employed by applicants' preferred embodiment of the invention as illustrated by Figure III, is that the preheating, retorting and fractionation of oil shale and shale oil are carried out in a manner similar to the method described with reference to Figure II except, however, the oxygen requirements of the process are greatly reduced and more efficient utilization of the available heat is achieved.

Referring now to Figure III, fresh crushed oil shale such as is found in vast quantities in the United States, particularly in Colorado, containing, for example, about 30 gallons of shale oil per ton by Fischer assay test, after being crushed to an average size of about one inch is fed from fresh oil shale hopper **120** by transfer means **121** into elevator-exchanger **124**. The elevator-exchanger is shown as a long, upright or inclined structure. Although it may have many forms it is preferably a bucket-type elevator with perforated bottoms in the buckets. An alternative would be to use a reciprocating feed device as shown in the drawing at **125**. The fresh crushed oil shale is moved upward within the elevator-exchanger and transferred by suitable means **126**, such as a screw conveyor, to retort **128**. The retort may be a large upright vessel lined with firebrick and containing distributing means **122** in the upper section near the top thereof so as to evenly distribute the fresh incoming oil shale within the retort. At the bottom of the retort is located suitable means **129**, such as shaking grates, which permit the hot spent shale which still contains an appreciable amount of carbon and other combustible material to drop therefrom. Also in the lower section of the retort and preferably above the shaking grates is located distributing means **130** which is supplied by line **131** with the hot gases and vaporized shale oil from contact coking reactor **133**.

Thus, the hot gases and vaporized shale oil conducted to the retort via line **131** move upwardly through and countercurrently contact the downward moving mass of fresh oil shale within the retort and supply heat and maintain the temperature within the retort in the neighborhood of from about 900° to about 1000° F., preferably at about 900° F., so as to drive off the shale oil from the oil shale therein.

The vaporized shale oil, swept along by the hot gases from the contact-coker, leaves the retort by line **132** which leads to the top section of the elevator-exchanger wherein the vaporized shale oil and hot gases contact the incoming fresh oil shale in direct countercurrent heat exchange, thereby preheating the fresh oil shale to retorting temperature while at the same time the vaporized

shale oil is condensed upon the oil shale. The condensed and liquefied shale oil flows downward through the oil shale to the bottom section of the elevator exchanger where it is drawn off by line 134. The non-condensed gases and vapors are drawn off from the elevator-exchanger at the same time via line 135 which is connected to the suction side of blower-eductor 136 from which they pass via line 138 to suitable cleaning, recovery and storage means for the recovery and/or separation of the valuable components thereof, such as ammonia and the light hydrocarbon gases. It is pointed out that in order to provide for a more complete recovery of the light, more volatile hydrocarbon fractions it may be desirable to interpose a condenser (not shown in Figure III) with a suitable coolant, such as water, shale oil product, air, etc., between line 135 and blower-eductor 136 in order to condense and remove the more volatile hydrocarbons from the ordinarily non-condensable gases.

In the operation of the process, hot spent shale from which shale oil has been driven off is dropped from the retort by shaking grates and then is delivered by suitable means 139 to a burning or combustion zone 140, for example, a furnace, which is equipped with a suitable device 141, such as an endless chain grate, for the combustion therein of the residual combustible matter on the hot spent shale from the retort. As pointed out hereinbefore the spent shale from the retorting zone contains a considerable amount of combustible matter, such as carbon. The combustible matter on the spent shale is burned within the furnace which is supplied with air or an oxygen-containing gas by line 142 to maintain a zone of combustion therein. This air or oxygen-containing gas may be preheated by contact with the hot shale ash from the furnace before being admitted to the combustion zone thereof. The hot gaseous products of combustion on leaving the furnace pass through a heat-exchange zone 144 and are then dissipated into the atmosphere by stack 145 which is connected to the heat-exchange zone. The hot solid products of combustion (shale ash) are discharged from the furnace by the endless chain grate and conveyed by means 145 to the contact coking reactor 133.

The liquefied shale oil from the elevator-exchanger is conducted by line 134 through heat exchange zone 144, wherein the temperature of said shale oil is raised to from about 600° to about 800° F., preferably in the neighborhood of 700° F., into fractionator 148. Therein the shale oil may be fractionated into three fractions, a top light fraction with an end boiling point up to about 400° F., which is drawn off as a product by line 149, a middle, medium fraction with an end boiling point of about 600° F., which is drawn off as a product by line 150 and a bottom, heavy high boiling (tarry) fraction which is drawn off by line 151. Pump 152, the suction side of which is connected with line 151 and the discharge side of which is connected to line 154 acts in combination as a reboiler, the liquid bottoms fraction being passed through and heated via line 154 within the heat exchange zone and then returned to the fractionator.

It is, of course, realized that it may not be desirable to take off two product streams from the fractionator as described above. Thus, it is possible, and at times preferable, to take off all the liquid shale oil product overhead by line 149, eliminating the side-cut medium boiling fraction and to draw off a bottoms fraction by means of valved line 155, which connects with line 154, in sufficient quantity to maintain the desired heat-exchange relationships throughout the process after injection into the contact coker reactor.

Valved line 155 withdraws at least a portion of the fractionator bottoms fraction from reboiler line 154 and passes said bottoms fraction through the furnace heat-exchange zone for a time sufficient to bring its temperature up to from about 800° to about 1000° F., preferably 900° F., and then inject it into the contact coking reactor via lines 156, 158 and 159 at a point or points determined by the contact time desired and/or the operating conditions.

Contact coking reactor 133 is an upright reaction chamber wherein contact coking of the high boiling, heavy bottoms fraction from fractionator 148 is accomplished. The reactor contains a mass of hot shale ash supplied thereto by means 145 as the endless chain grate 141 permits the ash to drop from furnace 140. The shale ash is maintained therein at a sufficiently high temperature, from about 850° to about 1200° F., preferably in the neighborhood of about 900° F., to coke the high molecular weight components of the heavy bottoms fraction from the fractionator.

Reactor 133 operates in the following manner. A mass of hot burned spent shale (shale ash) almost completely filling the reactor and which may contain some residual unburned carbon, is maintained therein at a high temperature (in the range of 850° to 1200° F.). Although the shale ash is at least within this temperature range immediately after discharge from the furnace, due to radiation and other heat losses in addition to the heat required to coke the heavy bottoms shale oil fraction injected therein, it is necessary to supply heat to the reactor in order to maintain the desired operating temperature. This heat may be supplied by combustion of any residual carbon as the shale ash or the combustion of the coke deposited thereon as a result of contact coking the heavy bottoms fraction. Furthermore, this heat may also be obtained by the combustion of a portion of the injected shale oil. The aforesaid combustion may be maintained by a supply of oxygen or air or an oxygen enriched gas introduced into reactor, for example, at the lower section thereof, via line 160. In general the heat required to maintain the shale ash at coking temperature may be supplied by any suitable and convenient method, for example, the hot flue gases from stack 145 or superheated steam.

The mass of hot shale ash within the reactor is contacted therein with the heavy bottoms fraction from the fractionator and introduced into the reactor via line or lines 156, 158 and 159. The temperature of this heavy shale oil fraction is increased as it contacts the hot shale ash and percolates down therethrough and as a result the high molecular weight components thereof are thermally decomposed with the resultant formation of some coke and lower molecular weight hydrocarbons.

As pointed out hereinbefore with reference to Figure II, the contact coking which is carried out within the reactor 133 is not equivalent to or similar to catalytic cracking. In catalytic cracking the cracking temperature is kept low in order to maintain a higher catalytic activity of the catalyst employed. Furthermore, the oil fraction to be cracked is selected so that very little or no coke is formed upon cracking since coke formation is undesirable because it considerably reduces catalyst activity and life. Furthermore for this particular application contact-coking has been found to be a satisfactory method of treating a heavy shale oil fraction to convert the same into a usable and less troublesome product.

As pointed out hereinbefore, it is realized that it may be desirable to eliminate the middle side cut fraction taken off as product via line 150 from the fractionator and to increase the amount of the heavy bottoms fraction injected into reactor in order to supply the requisite hot vapors from the reactor to the retort, which vapors are necessary to heat the oil shale therein and to strip the shale oil therefrom. It is also possible by means of valved line 161 which connects lines 131 and 132, the inlet and outlet vapor lines of the retort, respectively, to by-pass the retort with at least a portion or all of the hot shale oil vapors from the reactor. This may be advantageous in order to avoid excessive pressure drop through the retort when a large volume of gas and/or vapors are passed therethrough. No loss of heat occurs since the hot vapors from line 161 are carried via line 132 to contact and preheat the fresh incoming oil shale in the elevator-exchanger. It is also desirable to supply oxygen via line 123 to distributing means 130 in the lower section of the retort so as to supply at least a portion of the heat required to retort oil shale by the combustion of the residual carbon on the oil shale. The combustion gases also serve to sweep out shale oil vapors from the retort via line 132.

The hot shale ash, after being stripped of possible shale oil values by low pressure steam introduced into the lower section of the reactor via line 162 beneath line 160, is continuously discharged from the reactor at a suitable temperature, for example, in the range from about 500° F. to about 900° F. by suitable means 164, such as shaking grates. The hot discharge shale ash which contains coke deposited thereon as a result of contact-coking the heavy shale oil fraction as well as perhaps some residual carbon, may be used as fuel to supply at least a portion of power, steam and heat requirements of a

plant carrying out the above-described process or the heat may be recovered therefrom by heat-exchange, such as with air to preheat the same before entering the furnace.

Illustrative of the operating conditions and the material and heat requirements per ton of oil shale of a method of retorting oil shale according to a process of the invention, such as is represented by Figure III, the following data are presented below. It should be noted that the heat and material requirements will vary over rather wide limits depending upon operating conditions such as time and temperature of retorting and contact coking, shale oil content of the oil shale retorted, etc.

Shale oil content per ton of oil shale (Fischer assay test).	30 gals.
Retorting temperature	900° F.
Contact coking temperature	900° F.
Oxygen requirement in retorting	About 150 s. c. f.
Temperature of gases leaving retort	900° F.
Heat required to raise oil shale temperature from 60° F. to 900° F.	550,000 B. t. u.
Heat delivered to oil shale by retort products.	120,000.
Temperature of gases leaving contact-coker.	900° F.
Quantity of heavy oil recycle to contact-coker.	80 gals.
Heat delivered to oil shale by coked recycle oil.	430,000 B. t. u.
Oxygen required in coking	About 150 s. c. f.
Temperature of shale ash from contact-coker.	850° F.
Stripping steam for contact-coker	About 10 lbs.

The above-described process, as illustrated by Figure III, despite its many advantages over the process as illustrated by Figure II is still very similar thereto, the main difference being the use of a separate combustion zone in the process of Figure III rather than maintaining a combustion zone with the retort as in the process of Figure II. Also the heat of retorting in the process of Figure III is supplied by hot shale oil vapors whereas in the process of Figure II a considerable part of the heat is supplied by the hot combustion gases. Thus, in view of the similarity of the processes as illustrated by Figures II and III, the many variations, combinations and modifications described and indicated hereinbefore with respect to the processes of Figure I and II are also applicable to the process as illustrated by Figure III.

Another feature of the invention is that the preheating and retorting operations may be carried out without employing the oxidative cracking step or the contact-coking step in combination with the oil shale retorting step. This embodiment is illustrated in Figure IV which schematically shows an apparatus adapted for carrying out this particular method.

Referring now to Figure IV, fresh crushed oil-shale is fed from fresh oil shale hopper **50** into preheater **51**. The fresh oil shale is moved upwardly within the preheater by any suitable means, such as a reciprocating feeder device **52**. When the oil-shale reaches the top section of the preheater it is transferred by suitable means, such as a screw conveyor or rotating ploughs **53**, driven by means **54** along conduit connecting means **55** into the top section of retort **56**. Air or oxygen is introduced into the lower section of the retort through line **57** to maintain a zone of combustion therein. Water may be introduced via line **58**, for the purpose as described with reference to the process illustrated by Figure I, that is, to cool and quench the hot spent shale and to thereby supply steam to the combustion zone. The lower section of the retort, below the zone of combustion, is equipped with a spent shale discharging means such as illustrated by means **59**. Thus, it is seen that the hot combustion gases and steam which is superheated as it passes through the combustion zone, arising from the zone of combustion travel upwardly, countercurrently to the downwardly moving body of oil-shale within the retort and drive off and strip the shale oil from the oil shale. The hot gases now commingled with vaporized shale oil then move through said conduit connecting means or vapor line (not shown in the drawing) in case a screw conveyor instead of a rotary plough was used, into the top section of the preheater and pass downward, countercurrently to the upwardly moving fresh oil shale which is heated by said hot gases and at the same time serves to condense the vaporized shale oil. The condensed shale oil is collected and removed by means of lines **60** and **61** and drawn off as a product through line **62**.

A modification of an embodiment of the invention described with reference to Figure IV is illustrated in Figure V.

In accordance with this embodiment, the retorting zone and the preheating zone of the apparatus represented in Figure IV are combined in a unified structure wherein the retorting zone is an upright annular zone surrounding the preheating zone, from which it is separated only by an upright dividing wall extending not all of the way to the top of the combination vessel and leaving at the inside top thereof a suitable inter-connecting space or opening for the free movement of particulate material from one zone to the other. More efficient heat transfer of heat from the retorting zone to the preheating zone is effected by use of the apparatus illustrated by Figure V.

Referring now to Figure V fresh, crushed oil shale is fed from oil shale hopper **70** into preheater (preheating zone) **71**. The fresh oil shale is caused to move upwardly within the preheater by any suitable means, such as reciprocating feeder **72**. When the oil shale reaches the top of the preheater it passes over to the retort (retorting zone) **74**. It should be noted that the preheater is mounted concentrically within the retort and that the annular space between the preheater and the retort serves as the retorting zone. Air or oxygen is admitted into the lower section of the retort by means **75** so as to maintain a zone of combustion therein. Water may be introduced via line **78**, if desired, for the same and similar purposes as described in connection with the processes as illustrated by Figures I and IV. The lower section of the retort, below the zone of combustion, is equipped with a spent shale discharging means such as illustrated by means **76**. Thus, the hot combustion gases (and superheated steam) arising from the zone of combustion travel upwardly countercurrently to the downwardly moving body of oil shale within the retort and drive off and strip the shale oil from the oil shale within the retort. The hot gases now commingled with vaporized shale oil after passing through the retort, then pass downwardly through the preheating zone countercurrently to the upwardly moving fresh oil shale, which is heated by said hot gases and which at the same time condenses the vaporized shale oil. The condensed liquefied shale oil product is collected by means **77** and/or **79** and drawn off as a product through line **80**.

Still with reference to Figure V it is pointed out that it is possible to carry out the process as illustrated by Figure V by modification of the apparatus thereof so that the relative location of preheater (preheating zone) and the retort (retorting zone) with respect to each other are reversed. That is, it is possible to employ the preheating zone of Figure V as the retorting zone (and the retorting zone) and the retorting zone of Figure V as the preheating zone. It is understood, of course, that the other necessary changes in the location and arrangement of the oil shale feeder and air, oxygen and/or steam supply lines must also correspondingly be made.

Another feature of the invention, which feature is employed by applicants' embodiment of the invention as illustrated by Figure VI, is that the preheating and retorting of oil shale are carried out in a manner somewhat similar to the method described with reference to Figure IV except that the heat required to bring the fresh incoming oil shale up to the retorting temperature is furnished by hot shale oil vapors which shale oil has previously been subjected to the temperature and pressures of the well known "viscosity-breaking" conditions. Furthermore, the combustion of the oil shale to supply the necessary heat for the process does not take place within the retort but rather in a zone separate therefrom, such as a furnace.

Referring now to Figure VI, fresh crushed oil shale such as is found in vast quantities in the United States, particularly in Colorado, containing, for example, about 30 gallons of shale oil per ton by Fischer assay test, after being crushed to an average size of about one inch, is fed from fresh oil shale hopper **170** by transfer means **171** into elevator-exchanger **172**. The elevator-exchanger is shown as a long, upright or inclined struc-

ture. Although it may have many forms it is preferably a bucket-type elevator with perforated bottoms in the buckets. An alternative would be to use a reciprocating feeder device as shown in the drawing at 174. The fresh crushed oil shale is moved upward within the elevator-exchanger and transferred by suitable means 175, such as a screw conveyor to retort 176. The retort may be a large upright vessel lined with firebrick and may contain distributing means 178 in the upper section near the top thereof so as to evenly distribute the fresh incoming oil shale within the retort. At the bottom of the retort is located suitable means 179, such as shaking grates, which permit the hot spent shale containing an appreciable amount of carbon and other combustible material to drop therefrom. Also in the lower section of the retort and preferably above the shaking grates is located distributing means 180 which is supplied by valved lines 181 and 182 carrying hot vaporized shale oil and oxygen or air, respectively.

Thus, the hot gases move upwardly through and countercurrently contact the downward moving mass of fresh oil shale within the retort and supply the heat necessary to maintain a retorting temperature within the retort, for example, in the neighborhood of from about 700 to about 1100° F., preferably within the range 900° 1000° F., at about 900° F., so as to drive off the shale oil from the oil shale therein.

The gases and vaporized shale oil leave the retort via line 183, enter line 184 which leads to the top section of the elevator-exchanger wherein the vaporized shale oil and hot gases contact the incoming fresh oil shale in direct countercurrent heat exchange thereby preheating the fresh oil shale up to retorting temperature while at the same time the vaporized shale oil is condensed upon the oil shale. The condensed and liquefied shale oil flows downward through the oil shale to the bottom section of the elevator-exchanger where it is drawn off by line 185. The non-condensed gases and vapors are drawn off from the elevator-exchanger via line 186 which is connected to the suction side of blower-eductor 187 from which they pass via line 188 to suitable cleaning, recovery and storage means for the recovery and/or separation of the valuable components thereof, such as ammonia and the light hydrocarbon gases. It is pointed out that in order to provide for a more complete recovery of the light, more volatile hydrocarbon fractions it may be desirable to interpose a condenser (not shown in Figure VI) with a suitable coolant, such as water, shale oil product, air, etc., between line 186 and blower-eductor 187 in order to condense and remove the more volatile hydrocarbons from the ordinarily non-condensable gases.

In the operation of the process hot spent shale from which shale oil has been driven off is dropped from the retort by the shaking grates and then delivered by suitable means 189 to a burning or combustion zone 190, for example, a furnace, which is equipped with a suitable device 191, such as an endless chain grate, for the combustion therein of the hot spent shale from the retort. As pointed out hereinbefore, the spent shale from the retorting zone contains a considerable amount of combustible matter such as carbon. The combustible matter on the spent shale is burned within the furnace which is supplied with air or an oxygen containing gas via line 192 to maintain a zone of combustion therein. The hot gaseous products of combustion on leaving the furnace, pass through heat-exchange zone 193 and are then dissipated into the atmosphere by stack 194 which is connected to the heat-exchange zone. The hot, solid products of combustion (shale ash) are discharged from the furnace by the endless chain grate and conveyed therefrom by means 195. The heat contained therein may be recovered by any suitable method, such as by heat-exchange with air to the furnace to preheat the same.

The condensed shale oil from the elevator-exchanger is conducted via line 185 to the suction side of pump 196 from which it is discharged via line 197 into a product run-down tank 198. A portion of the shale oil with the product run-down tank is removed as product via line 199 while another portion in sufficient quantity is withdrawn via line 200 to the suction side of pump 201 from which it is forced along line 202 to heat-exchanger 203 located within the heat-exchanger zone. The shale oil recycle from product run-down tank enters heat-exchanger 203 at a temperature of about 100° F. and emerges therefrom via line 184 at a temperature in the range of about 800° to about 900° F., preferably about 850° F., etc., shale oil having been subjected therein to viscosity-breaking conditions of temperature and pressure, for example, a temperature from about 800° to about 950° F. under a pressure of from about 200 to about 500 lbs. per square inch.

From heat-exchanger 203 the hot shale oil moves along line 184 from which a portion or all of the shale oil may be admitted via line 181 into the retort in order to heat and drive off shale oil from the oil shale therein. The gaseous products from the upper section of the retort leave via line 183 which is connected with line 184 and along which they are then conducted to the elevator-exchanger.

It may be desirable in order to maintain a retorting temperature within the retort to admit a supply of oxygen or air thereto via line 182. The oxygen unites with the combustible matter on the oil shale and thereby supplies the small amount of heat necessary to maintain the desired retorting temperature. It is possible and sometimes desirable in the operation of the process for the shale oil vapor to by-pass the retort completely and pass directly to the elevator-exchanger. This may be advantageous if the pressure drop through the retort is too great. This is possible since the oil shale from the elevator-exchanger will thereby be brought up to retorting temperature before admission into the retort and since retorting shale oil from oil shale is primarily a soaking operation, very little heat being required to actually vaporize shale oil from oil shale once the retorting temperature has been reached.

Illustrative of the operating conditions and the material and heat requirements per ton of oil shale of a method of retorting oil shale according to a process of the invention, such as is represented by Figure VI, the following data are presented below. It should be noted that the heat and material requirements will vary over rather wide limits depending upon operating conditions such as time and temperature of retorting and contact coking, shale oil content of the oil shale retorted, etc.

Shale oil content per ton of oil shale (Fischer assay test):	30 gals.
Retorting temperature	900° F.
Oxygen requirements in retorting	About 150 s. c. f.
Temperature of gases leaving retort	900° F.
Heat required to raise oil shale temperature from 60° F. to 900° F.	550,000 B. t. u.
Heat delivered to oil shale by retort products:	120,000 B. t. u.
Quantity of recycle to viscosity breaker	80 gals.
Temperature of products from viscosity breaker.	850–900° F.
Heat delivered to oil shale by viscosity broken recycle.	430,000 B. t. u.

The processes of the present invention may be widely varied as to conditions of temperature, pressure, rate of through-put, amount of reactants, quality of product desired, etc., as brought out in the above descriptions. For obvious reasons, it is preferred to operate the invention at about atmospheric pressure.

The invention is adapted for the recovery of oils from any solid substance, but it is particularly directed to the recovery of shale oil from oil shale.

In addition, the foregoing description of the processes is not to be taken as limiting the invention since many variations of the processes, as pointed out, may be made by those skilled in the art within the scope of the invention.

We claim as our invention:

1. A system for recovery of shale oil from oil shale comprising in combination an upright heat exchanger, an upright retorting vessel and a cracking reactor, said upright heat exchanger provided therein with elevating means for elevating particulate solid material and provided therein with intermediate collecting means for liquefied product and further provided with liquid and gaseous collecting means in the bottom thereof, conduit means connecting the upper ends of said heat exchanger and said retort vessel and adapted for transferring particulate solid material from said heat exchanger to said retort vessel, said retort vessel provided with an outlet opening near the upper end thereof and further provided with two separate feed inlets near the bottom thereof one at a higher position than the other and a discharge

opening at the bottom for removal of particulate solid material therefrom, a first conduit means connecting said outlet opening near the upper end of said retort vessel with an inlet opening at one end of said cracking reactor, a second conduit means connecting said heat exchanger with an intermediate point of said first conduit means, means for introducing oxygen into said first conduit means between said intermediate point and said cracking reactor, said cracking reactor provided with an outlet opening at the other end thereof and conduit means connecting said outlet opening of said cracking reactor with the upper section of said heat exchanger.

2. An apparatus for the recovery of shale oil from oil shale comprising a unified upright retorting structure closed at the top and having an annular zone formed by an upright wall extending within said retorting structure not all the way to the top of said retorting structure permitting inside the top of said retorting structure free movement of particulate material across the top of said upright wall, said unified structure being provided at the outside lower section thereof with inlet openings adapted for the passage of oxygen and steam therethrough, with a lower outlet opening adapted for the passage of particulate spent oil shale from said annular zone, and with an inlet opening adapted for the passage of particulate fresh oil shale into the enclosed space formed by said upright wall, and said unified structure being provided at the bottom thereof with an outlet opening for the withdrawal of shale oil from said enclosed space, and plunger means associated with said unified structure for forcing the oil shale in a compact column upwardly through said enclosed space.

3. A method for the recovery of shale oil from oil shale which comprises; introducing preheated oil shale into the upper section of a retort; causing a bed of said preheated shale to move downward, countercurrently to a stream of hot combustion gases whereby heat is supplied to said oil shale; producing said combustion gases by maintaining through the use of oxygen a zone of combustion in the lower section of said retort; ejecting hot spent shale from said combustion zone of said retort into a contact-coking reactor; injecting into said reactor a heavy shale oil fraction to contact said hot spent shale therein; conducting the effluent shale oil vapors from said retort and said reactor at a temperature below the threshold temperature in admixture with oxygen to an oxidative cracking reactor and effecting oxidative cracking of the admixture therein; conducting the effluent vaporous oil-containing product from said oxidative cracking reactor to contact in direct counter-current heat exchange relationship with fresh oil shale in a preheating zone to produce said preheated oil shale and to condense a portion of said vaporous products; removing liquefied shale oil from said preheating zone to a fractionating column and fractionating said liquefied shale oil to produce shale oil product and said heavy shale oil fraction.

4. A method for the recovery of shale oil from oil shale which comprises; introducing preheated oil shale into the upper section of a retort causing a bed of said preheated shale to move downward, countercurrently to a stream of hot combustion gases whereby heat is supplied to said oil shale; producing said combustion gases by maintaining through the use of oxygen a zone of combustion in the lower section of said retort; ejecting hot spent shale from said combustion zone of said retort; preheating a heavy shale oil fraction by indirect heat exchange with said hot spent shale; injecting said heavy shale oil fraction into the upper section of said retort above the combustion zone and thereby subjecting said heavy oil fraction to thermal decomposition; conducting the effluent shale oil vapors from said retort to contact, in direct countercurrent heat exchange relationship, with fresh oil shale in a preheating zone to produce said preheated oil shale and to condense a portion of said shale oil vapors; removing liquefied shale oil from said preheating zone to a fractionating column and fractionating said liquefied shale oil to product shale oil product and said heavy shale oil fraction.

5. An apparatus for recovery of shale oil from oil shale comprising in combination an upright heat exchanger, an upright retort vessel, a contact-coking reactor and a fractionating vessel, said upright heat exchanger provided therein with elevating means for elevating particulate solid material and further provided with liquid and gaseous collecting means in the bottom thereof, conduit means connecting the upper ends of said heat exchanger and said retort vessel and adapted for transferring particulate solid material from said heat exchanger to said retort vessel, said retort vessel provided with an outlet opening near the upper end thereof and further provided with a feed inlet near the bottom thereof and a discharge opening at the bottom for removal of particulate solid material therefrom, conduit means connecting said discharge opening of said retort vessel with an opening on the top of said contact-coking reactor, said contact-coking reactor provided with a bottom discharge opening for removal of particulate solid material therefrom and further provided with a feed inlet opening and a gas outlet opening, conduit means connecting said gas outlet opening of said contact-coking reactor and said outlet opening near the upper end of said retort vessel with the upper section of said upright heat exchanger, said fractionating vessel provided with a bottom discharge opening, a top discharge opening and a side feed inlet opening, conduit means connecting the bottom of said heat exchanger to said side feed inlet opening of said fractionating vessel, and conduit means connecting the said bottoms discharge opening of said fractionating vessel with said feed inlet opening of said contact-coking reactor.

6. A method for the recovery of shale oil from oil shale which comprises: introducing preheated oil shale into the upper section of a retort; causing a bed of said shale to move downward countercurrently to a stream of hot combustion gases and superheated steam whereby heat is supplied to said oil shale; producing said combustion gases by maintaining through the use of oxygen a zone of combustion in the lower section of said retort and producing said superheated steam by introducing water directly upon the hot spent shale from the zone of combustion at a point below the zone of combustion and simultaneously cooling said hot spent shale and superheating said steam upon upward passage of the steam to and through the combustion zone; ejecting the spent shale from the retort; cooling shale oil vapors emerging from said retort in a quenching zone with a heavy oil fraction produced in the process as hereinafter described to produce a shale oil mixture; conducting said mixture in intimate admixture with oxygen to a cracking reactor and effecting oxidative cracking of said mixture; contacting vaporous oil-containing product from said cracking reactor in direct countercurrent heat-exchange relationship with fresh oil shale in a preheating zone to produce said preheated oil shale and to condense a portion of said vaporous product; removing said heavy oil fraction as a condensate from an intermediate point of said preheating zone; removing the uncondensed gases and further liquefied product from said preheating zone and separating the water from said liquefied product.

7. A method for the recovery of shale oil from oil shale which comprises; introducing preheated oil shale into the upper section of a retort; causing a bed of said shale to move downward countercurrently to a stream of hot combustion gases and superheated steam whereby heat is supplied to said oil shale; producing said combustion gases by maintaining through the use of oxygen a zone of combustion in the lower section of said retort and producing said superheated steam by introducing water directly upon the hot spent shale from the zone of combustion at a point below the zone of combustion and simultaneously cooling said hot spent shale and superheating said steam upon upward passage of the steam to and through the combustion zone; ejecting the spent shale from the retort; cooling shale oil vapors emerging from said retort in a quenching zone with a heavy oil fraction produced in the process as hereinafter described to produce a shale oil mixture; conducting said mixture in intimate admixture with oxygen to a cracking reactor and effecting oxidative cracking of said mixture; conducting the vaporous oil-containing product from said cracking reactor to a converter to contact said vaporous oil-containing product with said spent shale so as to convert the oxygenated organic compounds resulting from the oxidative cracking step to the corresponding hydrocarbons; contacting the vaporous product from said converter in direct countercurrent heat-exchange relationship with fresh oil shale in a preheating zone to produce said preheated oil shale and to condense a portion of said vaporous product; removing said heavy oil fraction from an intermediate portion of said preheating zone; remov-

ing the uncondensed gases and further liquefied product from said preheating zone and separating the water from said liquefied product.

8. A method of retorting oil shale which comprises; introducing preheated oil shale into the upper section of a retort, causing a bed of said oil shale to move downward through a retorting zone in said retort countercurrently to a stream of hot combustion gases and superheated steam in proportions and sensible heat content and having a temperature sufficient to retort the oil shale to shale oil and spent shale; producing said combustion gases by maintaining through the use of oxygen and the spent shale from which shale oil has been substantially vaporized a zone of combustion in the lower section of said retort; producing said superheated steam by introducing water directly upon the hot spent shale from the zone of combustion at a point below the zone of combustion and simultaneously cooling said hot spent shale and superheating said steam upon upward passage of the steam to and through said combustion zone; and removing the cooled spent shale from the retort.

9. A method of retorting oil shale which comprises countercurrently contacting oil shale in a retorting zone with a combined stream of hot combustion gases and superheated steam in proportions and sensible heat content and having a temperature sufficient to retort the oil shale to shale oil and spent shale; producing said combustion gases by maintaining through the use of oxygen and the spent shale from which shale oil has been substantialy vaporized a zone of combustion in one end of said retorting zone; producing said superheated steam by introducing water directly upon the hot spent shale from the zone of combustion at a point downstream from the combustion zone along the direction of movement of the shale and simultaneously cooling said hot spent shale and superheating said steam upon upward passage of the steam to and through said combustion zone; and removing the cooled spent shale from the retort.

10. A method of retorting oil shale which comprises: introducing preheated oil shale into the upper section of an enclosed vertically extending retorting zone causing a bed of said oil shale to move downward through said retorting zone countercurrently to a stream of hot combustion gases and superheated steam whereby heat is supplied to said oil shale; maintaining through the use of oxygen a first zone of combustion in the lower section of said retorting zone to produce said hot combustion gases; burning shale from said first zone of combustion with air in a second separate zone of combustion; passing hot spent shale from said second separate zone of combustion to a separate shale quenching zone; quenching said hot spent shale by introducing water directly thereinto; contacting the resulting steam with hot combustion gases from said second separate zone of combustion in an external heat exchanger in indirect heat exchange relationship to produce said superheated steam; introducing said superheated steam into said retort at a point below said first zone of combustion; cooling shale oil vapors emerging from said retort in an oil quenching zone with a heavy oil fraction produced in the process as hereinafter described to produce a shale oil mixture; conducting said mixture in intimate admixture with oxygen to a cracking reactor and effecting oxidative cracking of the mixture; conducting the vaporous oil-containing product from said cracking reactor to a converter to contact said vaporous oil-containing product with said spent shale which has been pretreated with a mineral oxy-acid so as to convert the oxygenated organic compounds resulting from the oxidative cracking step to the corresponding hydrocarbons; contacting the vaporous product from said converter in direct countercurrent heat exchange relationship in a preheating zone to produce said preheated oil shale and to condense a portion of said vaporous product; removing said heavy oil fraction as a condensate from an intermediate point of said preheating zone; removing the uncondensed gases and further liquefied product from said preheating zone and separating the water from said liquefied product.

11. A method for the recovery of shale oil from oil shale which comprises: causing fresh oil shale to move upwardly through a preheating zone in direct, countercurrent heat exchange relationship with product shale oil vapors to preheat said shale and to condense a portion of said product shale oil vapors; permitting free movement of preheated oil shale from the upper section of the preheating zone to the upper section of a separate contiguous retorting zone; causing said oil shale to move downwardly through the retorting zone countercurrently to a stream of hot combustion gases and superheated steam whereby heat is supplied to said oil shale to obtain said product shale oil vapors and whereby fresh oil shale in the preheating zone is further preheated by indirect heat exchange relationship with the oil shale in the retorting zone to produce said preheated oil shale; producing said combustion gases by maintaining through the use of oxygen a zone of combustion in the lower section of said retorting zone; producing said superheated steam by introducing water directly upon the hot spent shale from the zone of combustion at a point below the zone of combustion, whereby said hot spent shale is simultaneously cooled, and superheating the resulting steam upon upward passage of the steam to and through said combustion zone; removing cooled spent shale from the retorting zone; and removing condensed shale oil from the lower section of the preheating zone.

References Cited in the file of this patent

UNITED STATES PATENTS

Number	Name	Date
1,781,934	Snyder	Nov. 18, 1930
1,976,696	Ellis	Oct. 9, 1934
2,014,212	Seguy	Sept. 10, 1935
2,264,427	Asbury	Dec. 2, 1941
2,317,379	Hemminger	Apr. 27, 1943
2,369,523	Belchetz	Feb. 13, 1945
2,371,147	Burk	Mar. 13, 1945
2,406,810	Day	Sept. 3, 1946
2,489,702	Coast	Nov. 29, 1949