Sept. 2, 1969 J. D. BENNETT 3,464,892

TUNNEL OVEN WITH A SERIES OF MOVING BARGES AND SEPARATE COMPARTMENTS

Filed May 23, 1967 3 Sheets-Sheet 1

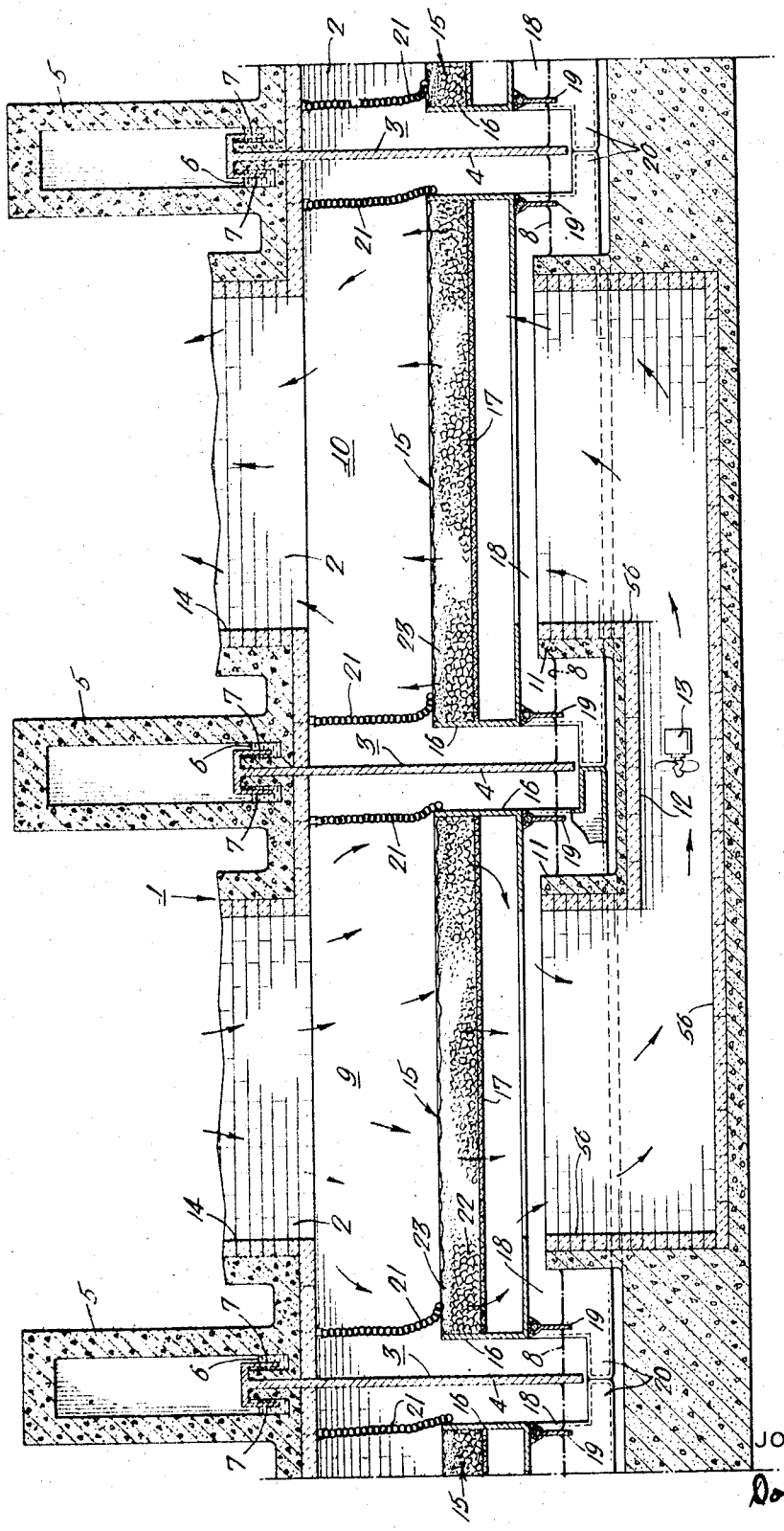


FIG. 1.

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TUNNEL OVEN WITH A SERIES OF MOVING BARGES AND SEPARATE COMPARTMENTS

Filed May 23, 1967 3 Sheets-Sheet 2

FIG. 2.

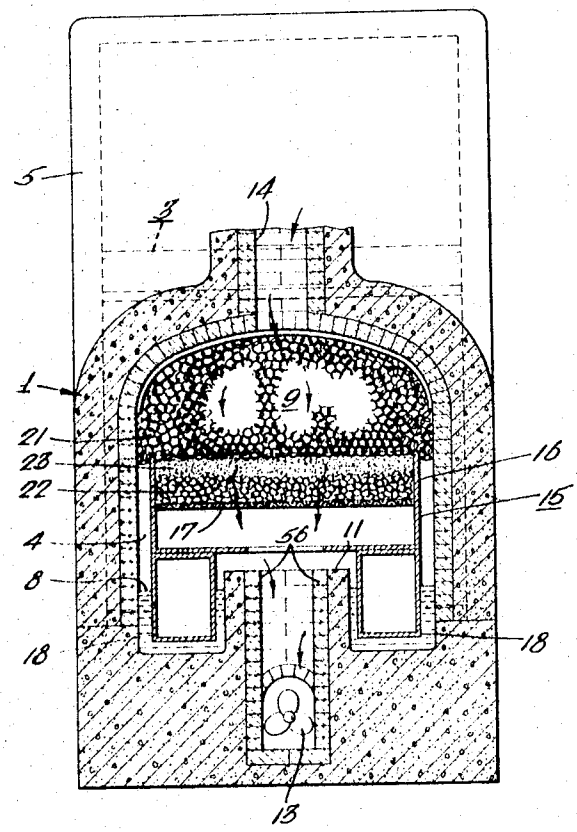
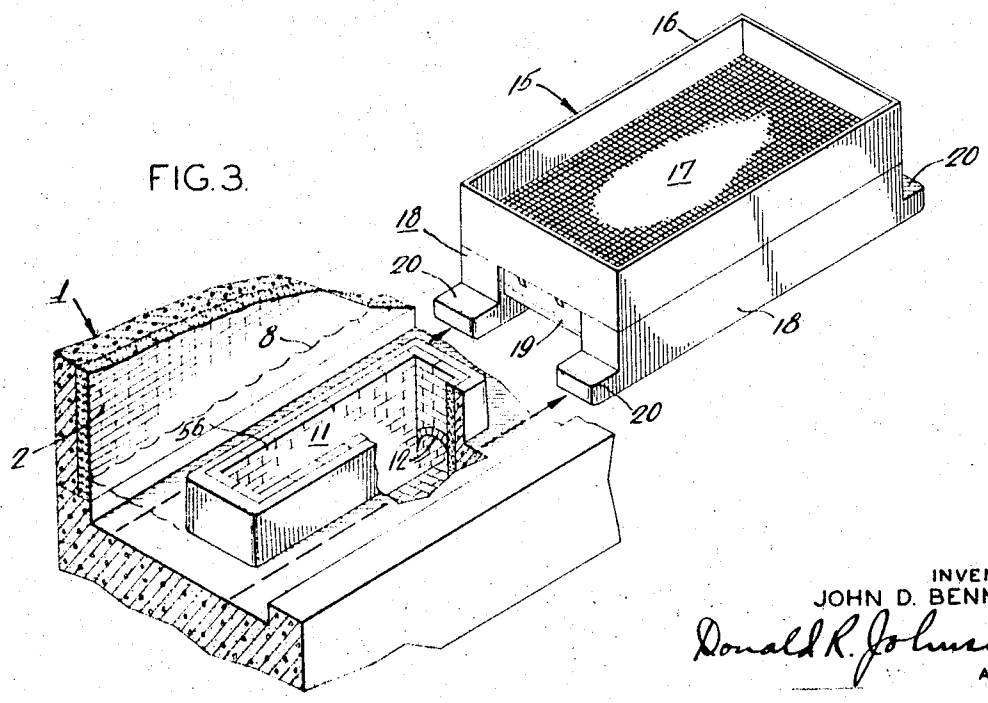


FIG. 3.



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Filed May 23, 1967 3 Sheets-Sheet 3

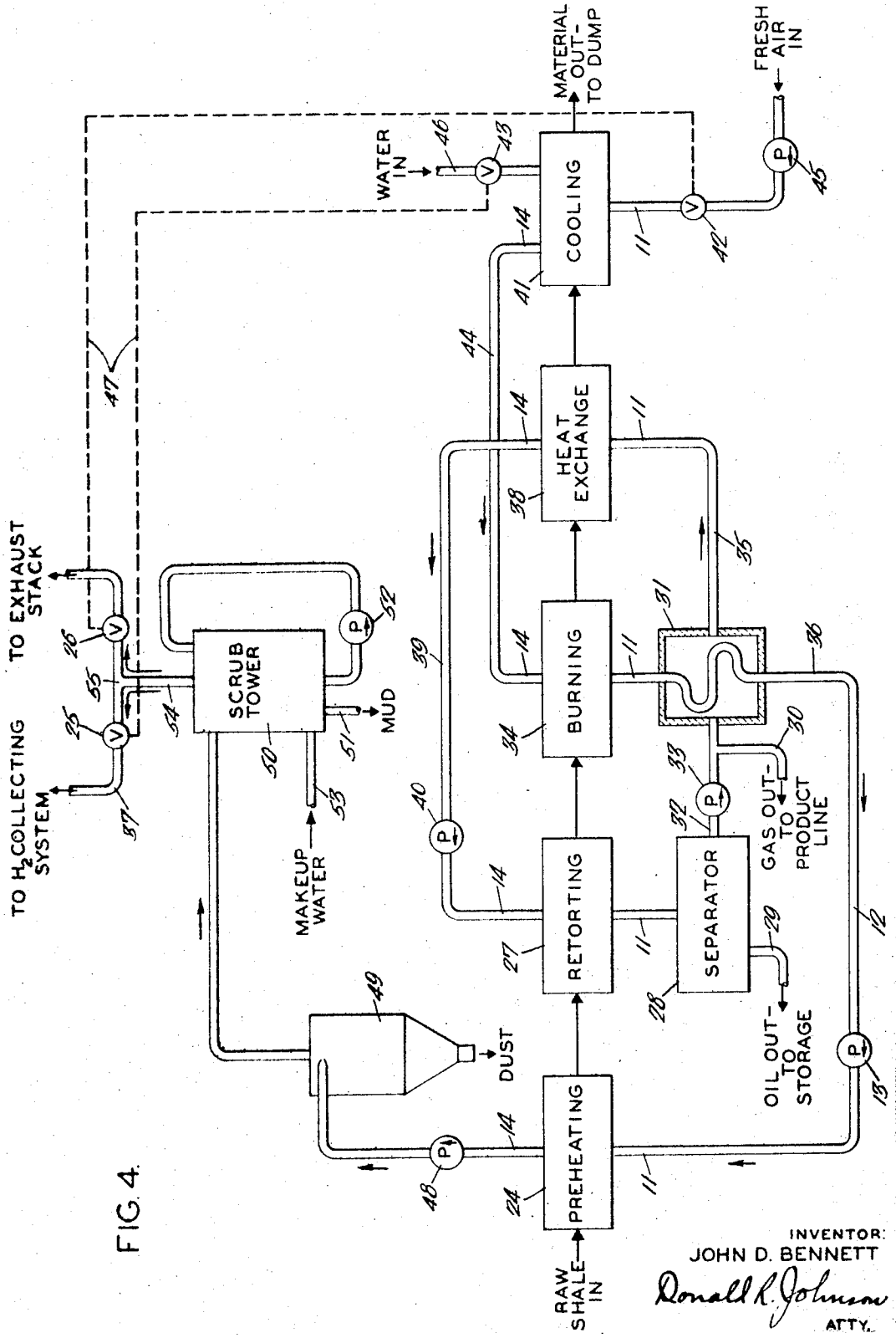


FIG 4.

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United States Patent Office 3,464,892 Patented Sept. 2, 1969

3,464,892

TUNNEL OVEN WITH A SERIES OF MOVING BARGES AND SEPARATE COMPARTMENTS

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Filed May 23, 1967, Ser. No. 640,752
Int. Cl. C10b 53/06, 7/14, 1/00
U.S. Cl. 202—98 6 Claims

ABSTRACT OF THE DISCLOSURE

A tunnel oven for gaseous treatment of solid material is separated by gas-tight partitions into a number of compartments in each of which a separate treatment step may be carried out. A series of barges, which carry the solid material and which float on liquid in the tunnel, are moved step-by-step from one compartment to another. Inlet and outlet ducts, which open into the tops and bottoms of each compartment, convey the treating gases through the compartments. The ducts are sealed to the barges, so that the gases are made to pass through the solid material. The tunnel oven may be used for the retorting of oil shales, and a process using the oven is disclosed, this process including as a step the burning of the carbonaceous residue remaining on the shale after the same has been retorted.

This invention relates generally to a tunnel oven for the retorting of carbonaceous solid materials such as oil shales, oil sands (tar sands), coals, lignite, and the like; such solids ordinarily contain volatilizable constituents. More particularly, it relates to that class of tunnel ovens in which the solid material to be treated is supported by a vehicle having a bottom permeable to gas, this vehicle being moved from one position to another in a suitable manner intermittently. Heating, viz. distilling or retorting of the material, is effected by a direct contact with hot gases which are introduced under or over the supporting bottom permeable to gas and which are forced through the material to be treated by means of fans mounted in gas-conveying ducts, while the vehicles themselves are sealed to such ducts in order to force the entire gas flow to pass through the material. The invention is concerned with a novel retorting oven and with an improved process using the oven.

Tunnel ovens of the class to which this invention relates are divided by vertical partitions into compartments in each of which a separate treatment step is carried out. In accordance with the present invention, these partitions comprise gas-tight doors around the edges of which liquid seals are provided.

The tunnel oven of the present invention contains a liquid, and the vehicles employed for supporting and transporting the material to be treated comprise barges which float on this liquid. The aforementioned sealing of the vehicles (barges) to the gas-conveying ducts is effected by utilizing the liquid in the tunnel to form liquid seals.

The apparatus of the invention will be described below using the distillation of oil shales as an example for the utilizing of the process of the invention. It is noted, however, that systems of this type may be used in a substantially analogous manner for the distillation or carbonization of other carbonizable materials such as those previously mentioned, and quite generally for the recovery of volatilizable constituents from subdivided solids (e.g., certain types of ores) containing the same.

A typical process using the oven of the present invention includes several steps in addition to the retorting step previously mentioned. Each of these treatment steps is carried out in a separate compartment or zone of the oven, and each steps involves the passage of a gas (or more generally, mixture of gases) through the solid material being treated, which latter is supported on a barge. One of these treatment steps will ordinarily comprise the burning of the carbonaceous residue which remains on the shale after the same has been retorted (that is to say, the carbonaceous residue on the spent shale or coked solids); the heat content of the material which has been so burned is utilized to provide the hot gases for retorting the fresh material.

An object of this invention is to provide an improved apparatus and process for recovery of oil from oil-bearing sands, shales, and the like.

Another object is to provide an improved process and apparatus for the efficient and inexpensive recovery of oil from oil-bearing sands, shales, and the like.

A further object is to provide a process and apparatus, for recovery of oil from oil-bearing solids, which will reduce atmospheric pollution.

A still further object is to provide a process for recovery of oil from oil-bearing solids which utilizes most of the energy developed in the process.

Still another object is to provide a process for recovery of oil from oil-bearing solids in which a valuable by-product may be produced without the expenditure of any energy over and above that already available in the process.

A still further object is to provide an improved process and apparatus, for recovery of oil from oil-bearing solids, which is essentially insensitive to particle size of the feed solids.

The objects of this invention are accomplished, briefly, in the following manner: A long tunnel oven containing a suitable flotation liquid is separated by movable gas-tight partitions into separate compartments, through which barges, carrying the solid material to be treated and floating on the liquid, are moved step-by-step from one compartment to another. Inlet and outlet gas-conveying ducts open into the tops and bottoms of the compartments, the gas flowing from each inlet duct to the outlet duct of the same compartment through the material in the respective barge, the barges having foraminous load carriers which permit this gas flow through the material to take place. The floation liquid is utilized to seal the bottom of the barge to the bottom duct in each respective compartment.

In each compartment, a separate treatment step is carried out. A typical process comprises the following steps: (1) In the first step (carried out in the first compartment), the fresh raw shale (after being loaded on the barge) is preheated to a temperature below the retorting temperature, by passing therethrough gases at an elevated temperature derived from a burning compartment. (2) In the second step (carried out in the second compartment), the preheated shale is retorted (distilled) to drive off volatilizable constituents (which are collected) by passing therethrough hot lean gases; these hot lean gases comprise non-condensable gases (derived from the volatilizable constituents) which are recycled through the process and are heated by contact with the hot solids in a heat exchange zone. The retorting of the shale causes the same to become spent, which leaves a carbonaceous residue thereon. (3) The third process step comprises the burning of the residue on the spent material, by passing there through a hot combustion-supporting gas which has been heated by contact with the hot solids in a cooling zone. From this burning operation are

derived the elevated-temperature gases which are utilized for heating the raw shale in the preheating zone. (4) The fourth step takes place in a heat exchange zone, wherein the hot solids derived from the burning compartment give up heat to recycled lean gases passing through this hot material. (5) The fifth and final step utilizes a cooling, wherein solids at an elevated temperature derived from the heat exchange zone give up heat to a combustion-supporting gas (e.g., fresh air) passing through this solid material. From the cooling compartment, the treated, decoked, and relatively cool material is unloaded from the barge and piled on a dump.

The process steps set out in the preceding paragraph actually each comprise two phases, the action described previously taking place during the first phase. In the second phase, the combustion-supporting gas (e.g., air) passed through the burning compartment (or zone) is replaced by steam, thereby generating hydrogen by a water-gas reaction. This steam is developed in the cooling zone. During this hydrogen-generating second phase, the generated hydrogen is led off to a hydrogen collecting system.

A detailed description of the invention follows, taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a vertical longitudinal sectional view of a portion of a tunnel oven apparatus according to this invention;

FIG. 2 is a vertical transverse sectional view of the tunnel oven apparatus;

FIG. 3 is an exploded view, in perspective, of a barge and a portion of the tunnel oven; and

FIG. 4 is a block diagram of a typical process using the tunnel oven.

A long tunnel oven, denoted generally by numeral **1**, is formed from concrete or some similar structural material. This tunnel may have a domed or arched shape in cross-section (set FIG. 2) and may typically have a length of about 500 feet and an inside width of about 25 feet. The interior of the oven may be lined with (refractory) firebrick as at **2**, so that the structure will be able to withstand high temperatures during operation.

At regular intervals along the length of tunnel **1**, there art provided movable partitions (denoted generally by numeral **3**) which divide the interior of the tunnel into isolated compartments. Two of these compartments, and portions of two others, are illustrated in FIGURE 1. By way of example, there may be five compartments altogether, which would call for a total of six partitions, including the two at the respective ends of the oven. Each of the movable partitions **3** comprises an imperforate door **4** which may be mounted for sliding movement either vertically or horizontally; in the drawings, these doors are illustrated as vertically slidable. These doors are somewhat analogous to the sliding "fire doors" commonly used in industrial establishments. Vertically-extending housings **5** are provided at spaced intervals in the top wall of the oven, one in alignment with each of the doors **4**, to receive the respective doors when they are slid upwardly to open position. A quantity **6** of a suitable sealing liquid (e.g., water) is provided in the bottom of each of the housings **5**, to furnish a liquid seal across the top of each door when the doors are in their closed positions. Each of the doors **4** has along its upper edge a pair of oppositely-disposed downwardly-extending flanges **7** which dip into the liquid **6** on opposite sides of the door when the door is in its closed (or lower) position, to form a liquid (gas-tight) seal at the top of each respective door.

To provide a gas-tight seal along the vertical sides of the doors **4** when the same are closed, water is pumped upwardly to the upper ends of these side edges by any well-known means (not shown), and is allowed to flow downwardly therealong to form liquid-wetted seals at the sides of the doors. Alternatively, an inflatable face-type gasket could be used on one face of each door **4**, adjacent to the vertical side edges thereof; in this case, means would be provided to inflate these gaskets when the respective doors are closed.

The liquid seal provided at the tops of the doors, plus the liquid-wetted seals provided at the vertical sides of the door, plus a liquid seal (to be later described) at the bottoms of the doors, cause the doors **4** to function as gas-tight partitions when they are in their closed positions. In this connection, it may be noted that these doors are illustrated in their closed positions in FIG. 1.

A body of a suitable flotation liquid, whose upper surface is indicated by the dotted line **8**, is provided in the tunnel **1**. This liquid may be water, a mixture (emulsion) of water and oil, or oil; if the latter, a high flash point oil should be used. When the doors **4** are in their closed (lower) positions, the bottom of each dips into the flotation liquid **8**, to provide a liquid (gas-tight) seal at the bottom of each respective door. Thus, when the doors **4** are in their closed positions, they provide gas-tight partitions between the various compartments of the tunnel, such as compartments **9** and **10**.

A separate vertically-extending gas-conveying duct **11** (which may be thought of as a "lower chimney") opens into the bottom of each respective one of the compartments such as **9** and **10** of the tunnel. The upper ends of all the bottom ducts **11** project upwardly above the liquid level **8**, so that liquid completely surrounds each of these lower chimneys. The bottom ducts have rectangular cross-sections; see FIG. 3.

Speaking generally, the bottom ducts **11** are connected into an appropriate laterally-extending connecting duct system in such a manner as to accomplish the desired process. The bottom ducts **11** can be connected to either other bottom ducts, or top ducts, of any other compartment. By way of example only, in FIG. 1 the bottom duct **11** of compartment **9** (which duct may serve as the outlet duct for this compartment) is connected by means of a horizontally-extending duct section **12** to the bottom duct of compartment **10** (which duct may serve as the inlet duct for this latter compartment). Bottom ducts **11** and duct section **12** are lined with (refractory) firebrick as at **56**.

The ducts **11** and **12** are intended to convey gases, and the gases are caused to flow through these ducts by means of fans such as that somewhat schematically illustrated at **13**.

A separate vertically-extending gas-conveying duct **14** (which may be thought of as an "upper chimney") opens into the top of each respective one of the compartments such as **9** and **10** of the oven. A conventional overhead connecting duct system is used to connect the top ducts **14** to other ducts (either top or bottom) in the same tunnel, or to connect these top ducts to ducts (top or bottom) in adjacent tunnels (if a two-tunnel arrangement is used), as required by the process. The refractory lining **2** extends into the top ducts **14**, as illustrated in the drawings.

Ducts **14**, like ducts **11**, are used to convey gases; in the illustration of FIG. 1, the top duct **14** of compartment **9** serves as the inlet duct for this compartment, while the top duct **14** of compartment **10** serves as the outlet duct for this latter compartment. In the setup illustrated in FIG. 1, as indicated by the arrows, the gases flow downwardly from the left-hand top duct **14** through compartment **9**, thence into the bottom duct **11** of this compartment and through duct section **12** to the bottom duct **11** of compartment **10**. Thence, the flow is upward through compartment **10** and into the top duct **14** of this latter compartment.

In order to support and transport the solid material which is to be treated through the tunnel, a series of barges which float on the liquid **8** is used, these barges being adapted to progressively move through the tunnel **1** from one compartment (such as **9**) to another (such as **10**) in step-by-step movements. As more clearly illus-

trated in FIG. 3, each barge **15** comprises an open-ended box **16** having a grate **17** sealed at its edges through the sides of the box. The grate carries or supports the load of solid material which is being treated in the tunnel oven. Box **16** is sealingly mounted atop a pair of spaced, parallel pontoons **18** which float in the liquid **8** of the oven and thereby cause the liquid to support the weight of the barge plus its load or contents. The pontoons **18** extend along two of the four sides of box **16**, at the bottom thereof. The pontoons **18** straddle the bottom duct **11** when the barge is in position in the corresponding compartment of the tunnel, and since these pontoons extend an apreciable distance below the upper surface **8** of the liquid in the tunnel, form a liquid seal along two sides of the bottom duct **11**, thereby to seal these two sides of the bottom duct to the bottom of the grate **17**.

A pair of hinged doors **19**, whose upper edges fit closely against the bottom edges of box **16** and whose side edges fit closely against the inner side walls of pontoons **18**, are mounted on barge **15**, one at each respective end of the box. As the barge moves into one of the compartments (such as **9** or **10**), the leading door **19** swings out of the way to allow the barge to straddle the bottom duct **11** in that compartment. Then, when this leading door clears the far end of the duct, the door swings down into the liquid **8** to form a liquid seal along a third side of the bottom duct **11**, thereby to seal this third side to the bottom of the grate **17**. The trailing door **19** remains partially submerged in the liquid **8** to form a liquid seal along the fourth side of the bottom duct **11**, thereby to seal this fourth side of the bottom duct to the bottom of the grate **17**.

It may be seen, from the foregoing, that the pontoons **18** and the doors **19** act in concert to provide a liquid seal conecting the bottom of the grate **17** to the bottom duct **11**, in each of the compartments of the tunnel. Thus, in each compartment, the bottom duct **11** is positively connected to the bottom of the barge grate **17**; the exact location of the barge **15** is not critical, so long, of course, as both of the doors **19** are in their "down" positions. Because of this liquid seal, the gas flowing from the inlet duct to the outlet duct in each of the tunnel compartments (such as **9** and **10**) is made to flow through the respective foraminous load carrier (grate) **17** and the load of solid material carried thereby, as indicated by the arrows in FIG. 1.

Instead of the swinging or hinged doors **19**, sliding doors could be used between the pontoons **18**; such sliding doors would be operated by a mechanism which would cause them to be lowered into the liquid after the barge **15** is in a position wherein it straddles the bottom duct **11**.

The individual barges forming the series or string of barges being moved through the tunnel may be properly spaced from each other by physical contact therebetween, under the sealing doors **4**. For example, each of the pontoons **18** may have, in the lower region of each of its ends, an integral outwardly-extending projection **20**, the projections **20** extending outwardly beyond the transverse vertical walls of the box **16**. The projections **20** of one barge **15** come into engagement with the similar projections **20** of the preceding and following barges, under the sealing doors **4** as illustrated in FIG. 1, to space the barges properly in the respective compartments of the tunnel. In connection with this physical contact between the barges, it is pointed out that a tugboat could be used as as motive power source or a propulsion means, to push the string of barges through the tunnel.

Alternatively, the proper spacing of the barges could be maintained if a propulsion device such as a pull chain (of the type ordinarily used in auto washing apparatus of the automatic type, and running under the door **4**) were used for moving the barges through the tunnel, the barges then being hooked onto properly spaced points on this chain.

It is desired to be pointed out that certain features of the invention (such as, for example, the liquid seals at the bottoms of the doors **4**, and the liquid seals connecting the bottom of the grate **17** to the bottom duct **11**) could be realized by loading the solid material to be treated on a railroad car, and then rolling it on a track located under the liquid surface **8**, through the tunnel oven or furnace. Of course, in this case, the railroad car would have to have a foraminous load carrier such as grate **17**. Or, some other type of container (with a foraminous load carrier) provided with wheels, and running on some sort of support beneath the liquid surface, could be used. This last arrangement would be particularly useful for a small-capacity apparatus, such as a pilot plant processing say 300 tons of material per day. Relatively small containers would provide a capacity on this order, but if such small containers were floating in the depth of liquid necessary to provide the desired liquid seals, they would be unstable. Therefore, some sort of wheels would be necessary to move such small containers through the furnace. However, the use of barges floating on a liquid is generally preferred for a full-size (large) apparatus, since the cheapest and most dependable type of transportation for bulk materials is barge (power requirements for moving a barge being the minimum).

For shielding the upper, exposed portions of the sliding doors **4** from radiant heat developed in the tunnel compartments, hanging members **21** are utilized. These members, each of which can be a wall of chains, are suspended from the upper wall of the tunnel **1**, at locations on opposite sides of each of the doors **4** and in approximate vertical alignment with the positions assumed by the respective vertical transverse walls of the barge boxes **16** when the barges **15** are in their operative or processing positions in the compartments. Each of the members **21** shields that area of its respective door **4** (on one side of the door) bounded by the top of the barge box **16**, the upper wall of the tunnel, and the side walls of the tunnel. The members **21** hang downwardly from the upper wall of the tunnel and are capable of swinging back and forth, if necessary, to allow the passage thereunder of irregular pieces of solid material (being carried by a barge) which may project upwardly above the top of barge box **16**.

At a location which is outside of the entrance end of the tunnel oven, a quantity of the solid material to be treated (e.g., fresh raw oil shale) is loaded onto each barge **15**, on top of the grate **17**. The loading of the barges preferably utilizes an elevated double chute or double feed hopper arrangement, the fresh feed solids being loaded into these hoppers by means of conveyor belts; in the chute or feed hopper arrangement, the material is classified by particle size, with one of the chutes or hoppers containing "fine" material (particles below a certain size) and the other containing "coarse" material (particles above this certain size). Preferably, in loading the barges a layer **22** of "coarse" material is put down first, directly on top of the grate **17**, and on top of this there is put down a layer **23** of "fine" material, the total depth of the two layers being, for example, about three feet. By way of example, each of the barges **15** may be twenty feet wide and one hundred feet long, thus having a capacity of six thousand cubic feet or one hundred tons of oil shale.

A series or string of barges is loaded one by one, in succession, with fresh raw material, and these barges move through the entrance end of the tunnel oven into the first compartment, and thence successively through the following compartments, in step-by-step movements. (The propulsion devices, which provide motive power for moving the barges have been previously descirbed by way of example.) It should be apparent that all of the sliding gas-tight doors **4** are raised to their open positions when movement of the barges from one compartment to another takes place. Following such move-

ment, and when the bottoms of the barge grates 17 have been positively connected to the bottom ducts 11 (by means of the liquid seals, as previously described) in the next following compartment, the doors 4 are lowered to their closed or sealing positions, so that gaseous treatment of the solid material carried by the barges may take place. Assume that the time of travel from one compartment to the next, plus the time of treatment in the "next" compartment, is fifteen minutes. Actually, the time required to move the barges from one tunnel compartment to the next (that is, to move the barges from one step in the process to the next) should be very small. As previously mentioned, successive steps in the treating process take place in successive tunnel compartments, from the entrance end to the exit end of the tunnel. For the assumed time of fifteen minutes per compartment, one barge (one hundred tons of material) will emerge from the exit end of the tunnel every fifteen minutes which means four hundred tons per hour of material is processed, or $25 \times 400 = 9600$ tons per day.

A typical oil shale treatment process (using the tunnel oven or barge retort apparatus of the invention) will now be described, with reference to FIG. 4. FIG. 4 discloses a process having five treatment or process steps, which would call for a tunnel divided into five compartments or zones. In some cases, however, because of the time requirements for other parts of the process, it might be found desirable to spread out the retorting step (distilling, or driving off the valuable volatilizable constituents) over two zones; in this latter event, there would be required for the process a tunnel having six compartments.

Referring now to FIG. 4, a load of raw shale carried by a barge passes through the entrance door of the tunnel and enters the first tunnel compartment 24 (which is exactly similar in construction to compartments 9 and 10, previously described). By the time this barge has been properly connected to the bottom duct 11 of this compartment (by means of the liquid seals, previously described), the sliding gas-tight doors at the ends of this compartment are closed, and the first treatment or process step begins.

For convenience, in describing FIG. 4 a single barge will be considered, and the effect of the various treatments or process steps on the contents of this barge will be described. However, it is to be remembered that during any one method step, the material carried by other barges is simultaneously being treated or processed. By way of example, while the barge load under consideration is being treated in the first compartment, the succeeding barge is loaded with raw shale, and the preceding barge load (in the series or string) is being treated in the second tunnel compartment.

Each of the five process steps previously referred to is divided into two phases, the barges remaining in their respective compartments or zones during both phases of a single process step. All of the process steps are affected, directly or indirectly, by this two-phase operation.

In the tunnel compartment or zone 24, the fresh raw shale is preheated (at atmospheric pressure) from an original temperature of about 80° F. to a temperature (of about 500° F., for example) which is just below the retorting temperature of the material. This preheating is effected by passing hot gases (including CO_2) upwardly through the material on the barge from the bottom inlet duct 11 to the top outlet duct 14 of compartment 24. The composition of the gases so passed through zone 24 varies from one phase to the other, as will be detailed hereinafter. The origin of these gases will be particularized hereinafter. Gases containing a small quantity of free oxygen are used for the preheating step, in order to prevent any damage-producing pre-ignition of the shale in the preheating stage or compartment or zone.

In the preheating zone 24, free water is driven off from the raw material (this water exiting from the top outlet duct 14 of zone 24), and this material is heated to just below the temperature at which volatilizable constituents begin to be driven off. A blower 48 moves the gases in the outlet duct 14 of preheating zone 24 (with the entrained water vapor) to a cyclone separator 49, which removes fine solid particles in the form of dust from the effluent. From separator 49, the separated effluent moves into a scrub tower 50, wherein scrubbing of this effluent takes place, using for scrubbing the free water which has been driven off (in zone 24) from the shale. Mud scrubbed out of the effluent leaves the scrub tower 50 by way of a pipe 51. The water is circulated in a loop including the scrub tower 50 by means of a pump 52, and any makeup water which is necessary is supplied to tower 50 by way of a pipe 53.

The scrubbed effluent (which has now had practically all entrained solids removed therefrom) leaves tower 50 via a pipe 54 which through a T 55 splits into two branches, one including a valve 25 and the other a valve 26. During the first phase of each process interval, hot flue gases (mainly CO_2) at a temperature of approximately 500° F. are supplied to the bottom inlet duct 11 of zone 24 (by way of duct section 12 and fan 13), and during this first phase valve 26 is open and valve 25 closed. During this first phase, then, the flue gases, after passing through separator 49 and scrub tower 50, are led off to an exhaust stack or vent which is coupled to valve 26. The fan or blower 13 is indicated schematically in FIG. 4 as a pump for gases.

During the second phase of each process interval, a mixture of hot steam, CO_2, and hydrogen (whose origin will be explained hereinafter, as will also the origin of the flue gases mentioned in the preceding paragraph) is supplied to the bottom inlet duct of zone 24, and during this second phase valve 26 is closed and valve 25 open. During this second phase, the matter leaving tower 50 at 54 is led off through valve 25, and through a pipe 37 coupled thereto, to a hydrogen collecting system.

Following the preheating, at the next "barge movement" interval (when the barges move on to the next succeeding compartments) the barge carrying the preheated shale enters the second tunnel compartment or zone 27 (again, exactly similar in construction to compartments 9 and 10). In the retorting zone 27, the preheated shale (at a temperature of around 500° F., for example) is heated to its retorting temperature (about 1100° F.), thereby driving off from the shale its volatizable constituents, which constitute valuable products. In order to provide the heat for the retorting zone, hot non-condensable or lean gases (methane and hydrogen) derived originally from the retorting zone are passed downwardly through the material on the barge in compartment 27 from the top inlet duct 14 toward the bottom outlet duct 11 of this compartment. The rich gas (volatizable constituents of the shale, volatilized as a result of the retorting, and containing both condensable and non-condensable gases) leaving compartment 27 via the bottom outlet duct 11 is fed through a separator 28 (a condenser-cooler), which condenses this gas, the oil condensed out being drained off to storage via a pipe 29. The non-condensable gases are sucked from the separator 28 by means of a pipe 32, to which a blower (gas pump) 33 is connected. The non-condensable gases being recirculated are fed from blower 33 to a heat exchanger 31, the non-condensable gases not needed for recirculation or recycling being drained off (to a product line) by means of a pipe 30.

The retorting of the shale in compartment 27 results in this material becoming spent, in which condition it may be termed a coked solid, since it has a carbonaceous residue (coke deposit) thereon.

Following the retorting step, the barge carrying the spent shale (coked solids enters the third tunnel compartment or zone 34. In the burning zone 34, the spent

shale is treated (during the first phase of the process interval) with a stream of heated combustion-supported gas (e.g., fresh air) to thereby burn the carbonaceous residue therefrom. During this burning phase, the solid material is raised in temperature from about 1100° F. to about 2000° F. The hot gas (air) required for burning (which gas is heated in a manner to be described hereinafter) is passed downwardly through the material on the barge in compartment **34** from the top inlet duct **14** toward the bottom outlet duct **11** of this compartment.

During the burning phase, almost all of the oxygen in the air fed to zone **34** is consumed, with the result that the flue gases leaving this zone at **11** (during this phase) consist mainly of carbon dioxide. These hot flue gases are fed to the gas-to-gas heat exchanger **31**, wherein they give up some of their heat to the non-condensable gases being fed thereto from separator **28**. This results, of course, in the raising of the temperature of the non-condensable gases being recirculated. The hotter non-condensable gases (which may be thought of as a gaseous mixture of methane and hydrogen) leave heat exchanger **31** by way of a pipe or duct **35**.

The cooler (but still hot) flue gases, after having had some of their heat removed by heat exchanger **31**, leave this exchanger by way of a conduit or duct **36** and are fed by way of duct section **12** and blower **13** to the bottom inlet duct **11** of preheating zone **24**. These hot flue gases (at a temperature of about 500° F.) provide (during the first phase) the heat for preheating the fresh raw shale, in preheating zone **24**. Since flue gases (containing only a small amount of oxygen) are used for the preheating during this phase, no substantial pre-ignition or burning can take place in the preheating zone **24**. When air is being supplied to the zone **34** during the first phase of the process interval, valve **26** is open and valve **25** closed, so that the flue gases produced, after heating the fresh raw shale, exit from the apparatus by way of the exhaust stack, after passing through separator **49** and scrub tower **50**.

During the burning phase (first phase of the process interval), sufficient heat is developed in zone **34** to clinker the "fines" **23** on the top of the barge load. Since clinkering is desired in the process of this invention, no close control on the oxygen during the burning phase is necessary (such close control being necessary in prior art processes, where clinkering was disadvantageous and was definitely not desired).

The first or burning phase, previously described, is one in which residual carbon (on the spent shale) is burned in zone **34** in order to obtain heat for the process. This providing of heat for the process is evidenced in one way by the heating of the non-condensable gases in heat exchanger **31**, these non-condensables being used thereafter for the retorting. As previously stated, during this first phase fresh air (preheated in a manner to be described) is fed to zone or compartment **34** for burning of the carbon residue on the spent shale therein. During this phase, oxygen in the form of air is present in compartments **41** and **34**, and, in a very small way, in compartment **24**. If the barges were stepped or shifted to the next or following compartments at the end of this first phase, internal explosions could occur, especially when the barge in zone **27** is moved to zone **34** (which latter would contain oxygen).

It is not necessary to consume all of the carbon residue on the spent shale in order to provide sufficient heat for the process. When enough heat has been liberated (by the burning taking place in zone **34**) to treat the batch of material being processed, and to clinker the "fines," the first phase ends with the cutting off of air to zone **34**, and with the supplying of steam to this zone, via the top inlet duct **14** of this zone. That is to say, during the second phase steam is supplied to zone **34**, rather than heated air as in the first phase. This steam (which travels also through zone **41**, as will be described subsequently) purges zones or compartments **41** and **34** of all oxygen. The hot steam will react (in zone **34**) with the remaining very hot carbonaceous residue on the material in this zone, converting the carbon to CO_2 and hydrogen by various well-known water gas reactions. The mixture of hot steam, CO_2, and hydrogen, which leaves zone **34** during the second phase, will continue to preheat zone **24** (and also to give up heat to the non-condensables, by means of heat exchanger **31**) until all of the residual carbon in zone **34** has been consumed, or else has cooled to a temperature such that hydrogen is no longer liberated.

While hydrogen is being liberated (during this second phase), valve **26** is closed and valve **25** is open. The hydrogen gas is then taken off to a suitable hydrogen collecting system, by way of a pipe **37** connected to valve **25**.

When the water gas reaction stops (i.e., when hydrogen is no longer liberated), valve **25** is closed and valve **26** is opened. Then, steam will continue to purge any air, or explosive gas, from compartment **24**. At the end of the process interval, all oxygen will have been purged from compartments **24**, **34**, and **41**, so there will be no oxygen present to cause explosions when the barges are stepped or shifted.

When all barges have been shifted and the doors **4** between the compartments closed, the next process interval begins, with the first phase.

Following the two phases of the process interval just described in connection with zone **34**, the shifting of the barges causes the hot shale (solids, now decoked) to leave zone **34** (at a temperature of about 2000° F.) and to enter the fourth tunnel compartment or zone **38**. In the zone **38** (which functions as a gas-to-solids heat exchanger), the non-condensable (lean) gases carried by pipe **35** (after having absorbed heat in heat exchanger **31**) are brought into contact with the hot spent and decoked shale, to absorb heat therefrom. The said non-condensables (methane and hydrogen, as previously stated) are passed upwardly through the material on the barge in compartment **38**, from the bottom inlet duct **11** to the top outlet duct **14** of this compartment. The hot non-condensable (lean) gases leaving zone **38** at **14** are fed by way of a pipe **39**, under the urging of a blower or fan **40**, to the top inlet duct **14** of retorting zone **27**; the hot gases in pipe **39** provide the heat for the retorting which takes place in zone **27**. The hot decoked solids in zone **38**, which give up heat to the non-condensables in this heat exchange zone, are cooled to about 1100° F. during this step of the process.

Following the heat exchange step, the spent and decoked shale (which still has a substantial heat content, due to its temperature of about 1100° F.) leaves the heat exchange zone **38** and enters the fifth tunnel compartment or zone **41**. In the zone **41**, the shale is cooled from about 1100° F. down to about 200° F. During the first phase of the process interval, this cooling is brought about by feeding the combustion-supporting gas (fresh air, which is fed to zone **34** during this same first phase) through zone **41**, to absorb heat from the heated spent shale. This preheats the air for feeding to zone **34**.

A pipe **46**, in which is located a control valve **43**, opens into the top of compartment **41**. A control valve **42** communicates with the lower inlet duct **11** of compartment **41**, and a fresh air blower **45** can supply fresh air through this valve to duct **11** of this compartment.

During the first phase of the process interval, valve **42** is open and valve **43** is closed. Fresh air, under the urging of blower **45**, then passes upwardly through the heated material on the barge in compartment **41**, from the bottom inlet duct **11** to the top outlet duct **14** of this compartment. The (preheated) air leaving zone **41** at **14** is fed by way of a pipe **44** to the top inlet duct **14** of zone **34**; the hot air in pipe **44** serves as a combustion-supporting gas for the burning phase (i.e., the first phase) which takes place in zone **34**.

As previously described, at the end of the first phase the air feed to zone **34** is cut off, this being done by

closing valve 42 to cut off the flow of air to zone 41. At this same time, to begin the second phase, valve 43 in water supply pipe 46 is opened. Water (which can be brackish) will then be sprayed on the heated material in zone 41, resulting in the production of steam and the consequent further cooling of the heated material in zone 41. This steam passes through zone 41 to the top outlet duct 14 of this zone, and then by way of pipe 44 into zone 34. As described hereinabove, the steam produced purges compartments 41 and 34 of all oxygen, and in addition reacts with the very hot residual carbon in zone 34 to convert it into CO_2 and hydrogen.

Valves 25, 26, 42, and 43 are operated in conjunction with each other at the beginning of the second phase of the process interval, as indicated by the dotted-line connections 47; at this particular point of time valves 42 and 26 are closed and valves 43 and 25 are opened.

In addition, there is another operating means (not shown) for valves 25 and 26, this operating means closing valve 25 and opening valve 26 when the water gas reaction stops during the second phase (i.e., when hydrogen is no longer liberated during the second phase); this action has been described previously.

It will be appreciated that the heated shale in the cooling zone 41 gives up heat during the first phase to heat the air for the combustion or burning phase (in zone 34), and gives up heat during the second phase to make steam (from water) for purging and for the water gas reaction in zone 34. This giving up of heat by the heated shale in zone 41 results in the cooling of the shale down to about 200° F. At this temperature, the shale is ready to be dumped.

The loading of the barges with solid material to be treated, prior to the preheating step, has previously been described. In some cases, this loading (which, of course, takes place outside the tunnel oven, adjacent the entrance end thereof) could be thought of as the first step in the process.

The cooled, spent, and decoked shale is unloaded from the barge following the cooling step, at a location which is outside the exit end of the tunnel oven. In some cases, this unloading could be thought of as the final step in the process. The unloading of the barges may be accomplished by utilizing equipment which picks each loaded barge up out of the liquid and dumps it, upside down, on a conveyor assembly, which latter then carries the unloaded material to the dump pile. In connection with the unloading, it is pointed out that the clinkers which are produced during the burning step present no particular problem, since they readily dump out of the barge along with the rest of the load.

Other methods could be used for unloading the barges. For example, the barges could be constructed with a pivoted grate arrangement which could be tripped at the unloading point, thus freeing the grate to rotate to open position to thereby allow the material to drop out the bottom of the barge box onto a conveyor belt.

The barge retort apparatus of this invention is capable of handling large volumes of raw material (oil shale). The process produces a gas (out of separator 28) of high B.t.u. value, one which is, moreover, uncontaminated with nitrogen. The process itself does not pollute the air, since the burning in zone 34 is clean and the flue gases vented or exhausted by the stack are mainly carbon dioxide.

Since the "fines" are clinkered during the burning step, the dump is "no blow," and there is no air pollution by the dump. Also, the clinkers stabilize the dump, preventing any accidental collapsing or sliding of the pile. In addition, the clinkers consolidate the dump so that it is not subject to erosion by water streams; thus, the dump does not pollute water streams. In this connection, note that the apparatus of this invention is able to handle clinkers with no difficulty whatever.

In the process disclosed, most of the available energy is utilized, since the material is sent to the dump only at a relatively low temperature. In this connection, it is noted that the power consumed is a minimum since barge transportation is used.

In the process of this invention, hydrogen is produced for upgrading the shale oil (by hydrogenation thereof) without the expenditure of any additional energy, that is, by utilizing the energy already available. Prior processes have commonly made hydrogen (for hydrogenation of the shale oil) from natural gas, which means a separate raw material and a separate, expensive process are required.

The apparatus of this invention is capable of processing or treating all material mined, and can handle shale of any richness.

It may be advantageous to employ a pair of tunnel ovens or barge retorts positioned side-by-side but arranged oppositely, such that the entrace end of one tunnel is beside the exit end of the other, and vice versa. In this case, one FIG. 4 duct arrangement would be used for one of the two tunnels (the barges moving from left to right on the drawing in this arrangement), and an exactly similar but reversed arrangement would be used for the other tunnel (the barges moving from right to left on the drawing in this reversed arrangement). In this double or two-tunnel system, the barges would be loaded and then moved in a forward direction through one tunnel; then they would be dumped, loaded with fresh material, and moved back through the other tunnel to the original point. The turnaround of the barges (i.e., the transference of the barges from one tunnel to the other at the two ends) could be of a circular type, or of a switch type.

The invention claimed is:

1. In an apparatus for gaseous treatment of solid materials, a tunnel made of non-porous material, partitions dividing said tunnel into compartments in each of which a separate treatment step may be carried out, a body of liquid in said tunnel, a series of barges floating on said liquid and adapted to progressively move through said tunnel from one compartment to another in step-by-step movements, said barges having foraminous load carriers; and inlet and outlet ducts opening into the tops and bottoms of each of said compartments for conveying treating gases therethrough, the gases flowing from inlet to outlet in each of said compartments through the respective foraminous load carrier and the load carried thereby.

2. Apparatus as defined in claim 1, wherein the upper ends of the ducts which open into the bottoms of the compartments project above the level of the liquid in said tunnel, said apparatus including also means carried by each barge and extending into said body of liquid, thereby to form a liquid seal around the edges of its foraminous load carrier and to thus seal its load carrier to the respective bottom duct.

3. In an apparatus for gaseout treatment of carbonaceous solid material such as oil shales and the lkie, a tunnel, partitions dividing said tunnel into compartments for successively retorting and then burning the material being treated, means for progressively moving through said tunnel from one compartment to another in step-by-step movements, vehicles having foraminous load carriers; inlet and outlet ducts opening into the tops and bottoms of each of said compartments for conveying treating gases therethrough, the gases flowing from inlet to outlet in each of said compartments through the respective foraminous load carrier and the load carried thereby, means coupled to the inlet duct associated with said retorting compartment for supplying hot gases thereto, means coupled to the outlet duct associated with said retorting compartment for collecting gaseous effluent from such compartment, means coupled to the inlet duct associated with said burning compartment for supplying a heated combustion-supporting gas thereto, thereby to burn the carbonaceous residue from the material in said

burning compartment, producing hot flue gases, and means coupled to the outlet duct associated with said burning compartment for utilizing the effluent flue gases from such compartment.

4. Apparatus in accordance with claim 3, including also means coupled to said collecting means for abstracting a portion of the gaseous effluent collected thereby, and means for heating the abstracted portion to provide the hot gases supplied to said retorting compartment; said heating means utilizing the heat content of the effluent flue gases in the burning compartment outlet duct and also utilizing the heat content of the solid material after burning.

5. Apparatus in accordance with claim 3, including also a preheating compartment preceding the retorting compartment, and means for feeding at least a portion of the effluent flue gases in the burning compartment outlet duct to the inlet duct of said preheating compartment.

6. Apparatus in accordance with claim 3, including also a heat exchange compartment following the burning compartment, means coupled to said collecting means for abstracting a portion of the gaseous effluent collected thereby and for feeding the abstracted portion to the

inlet duct of said heat exchange compartment, and means coupling the outlet duct of said heat exchange compartment to the retorting compartment inlet duct.

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