July 7, 1970 | E. V. SCHULTE | 3,519,539

APPARATUS FOR RETORTING OIL SHALE HAVING A CENTRAL AXIAL HOLLOW COLUMN

Filed Sept. 25, 1967 | 4 Sheets-Sheet 1

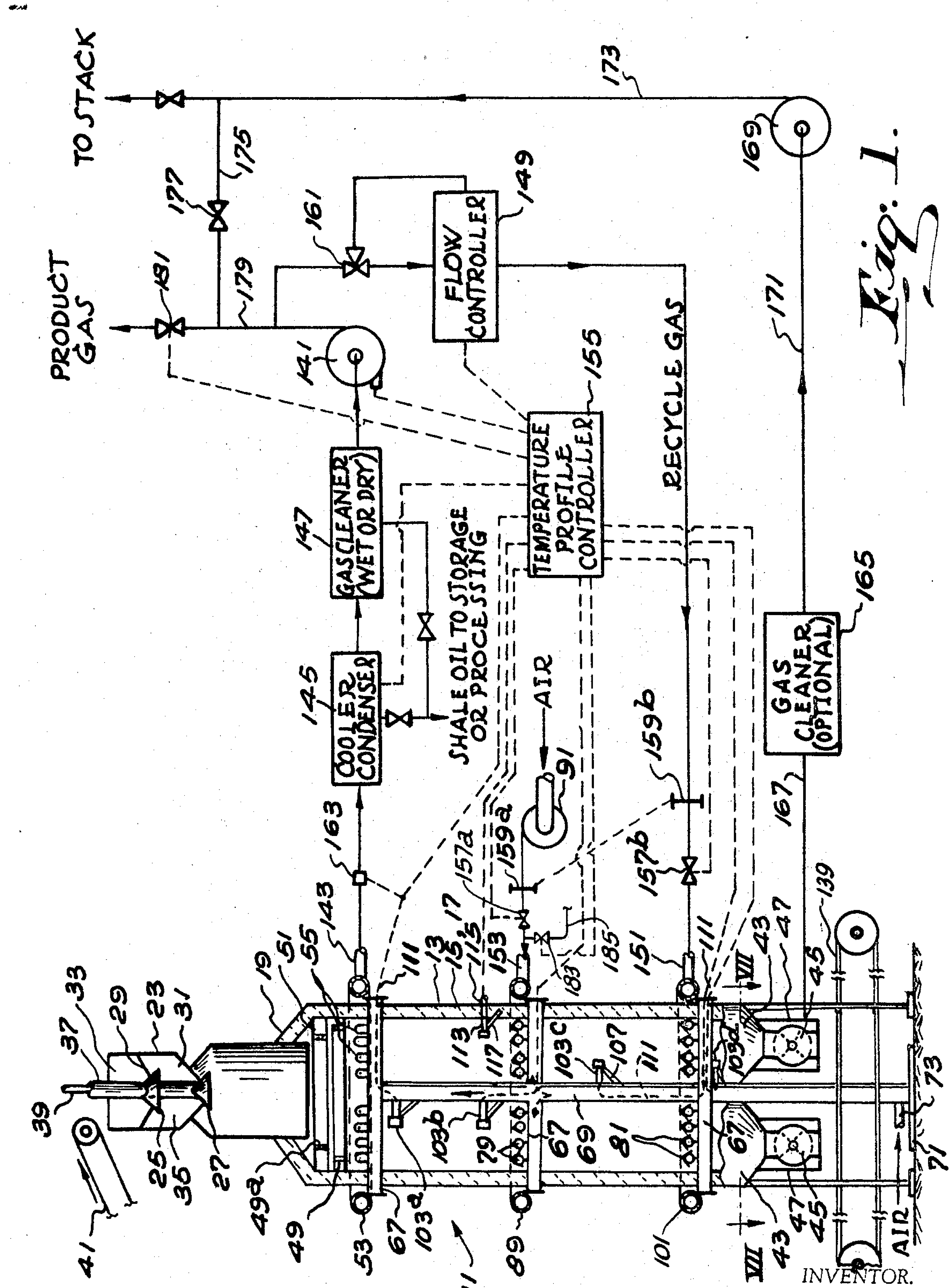

Fig. 1.

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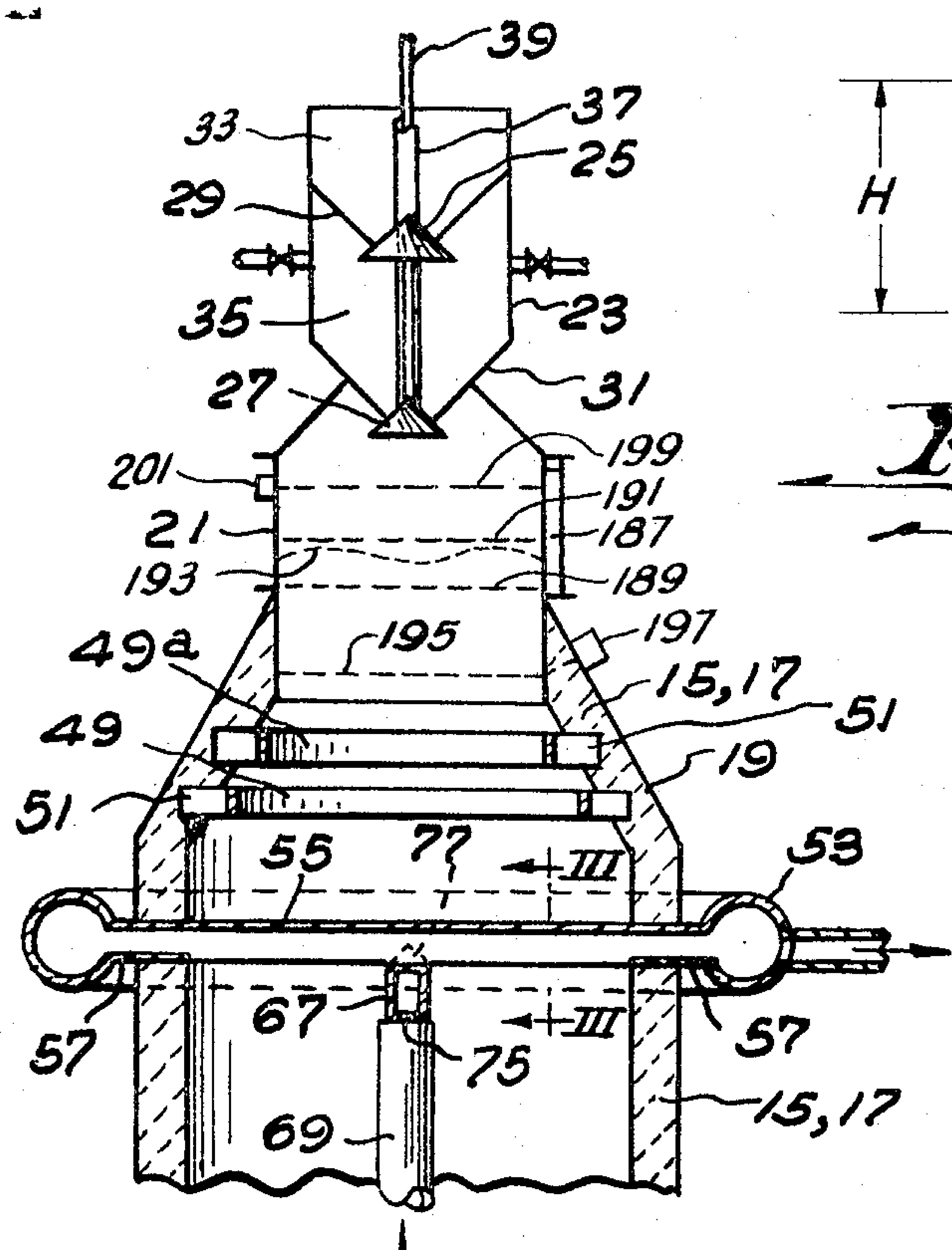

Fig. 2.

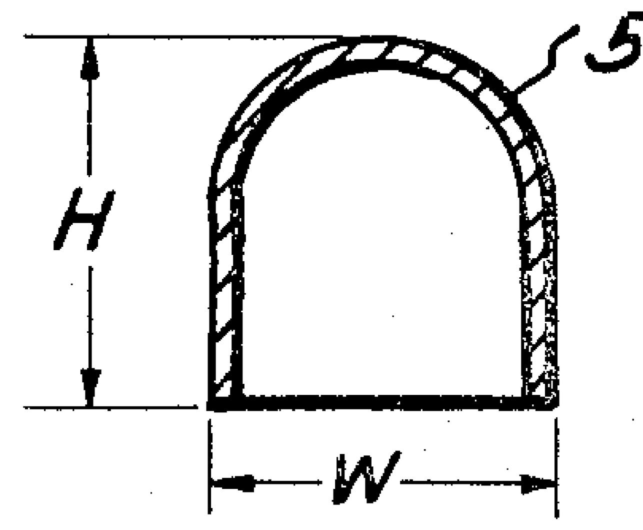

Fig. 3.

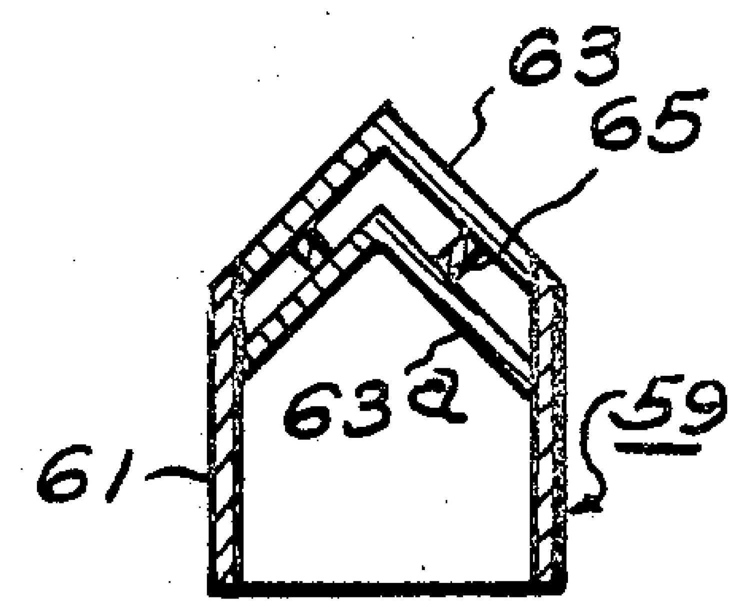

Fig. 3A.

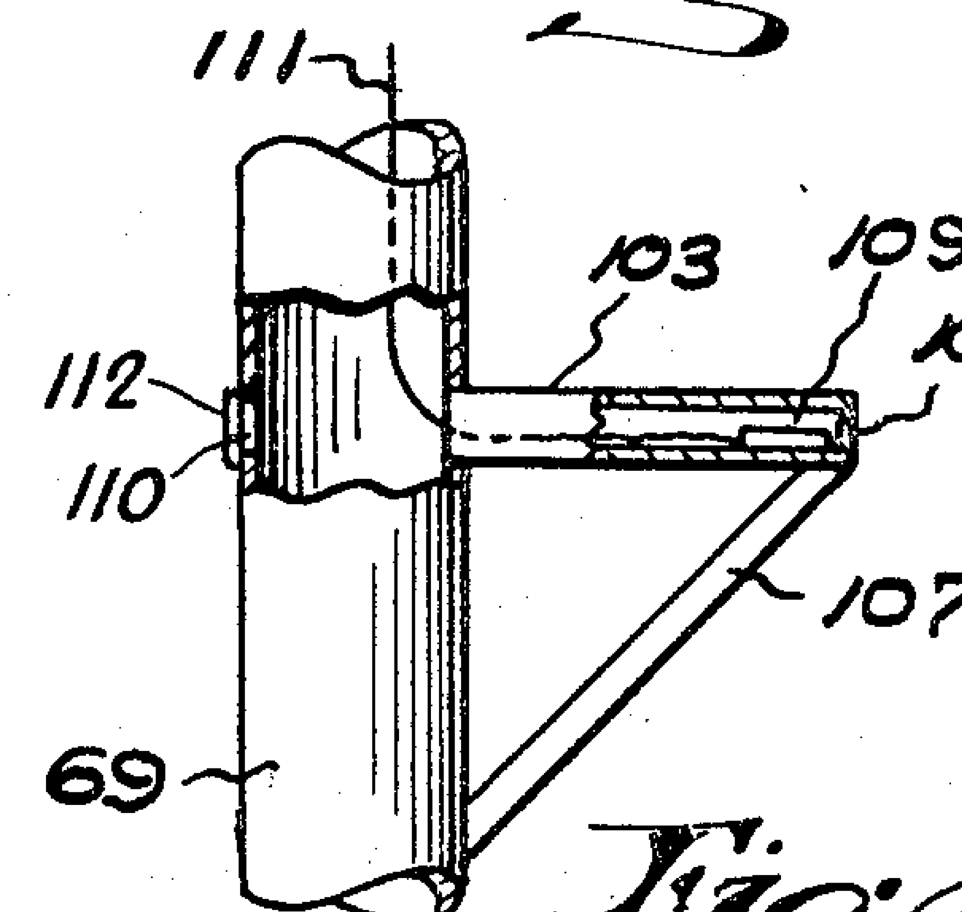

Fig. 4.

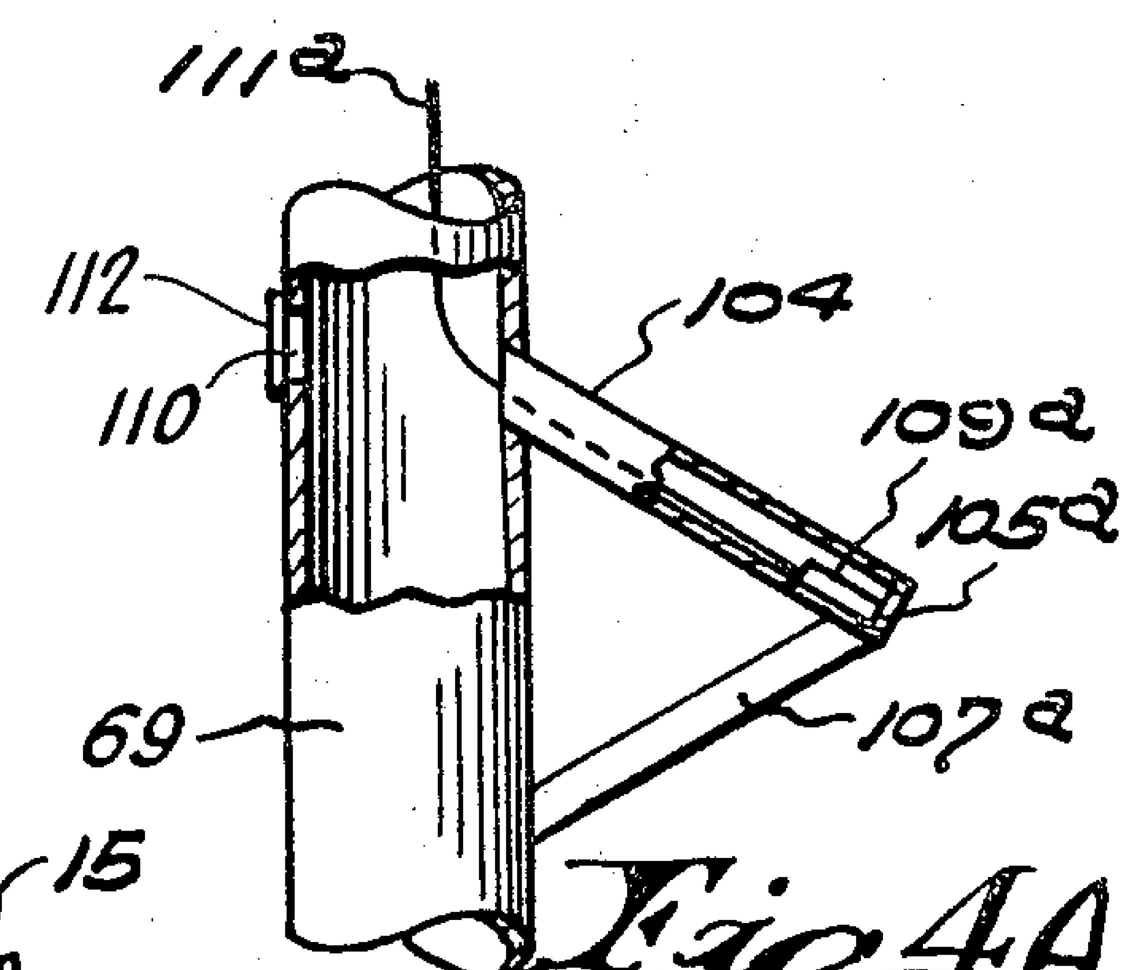

Fig. 4A

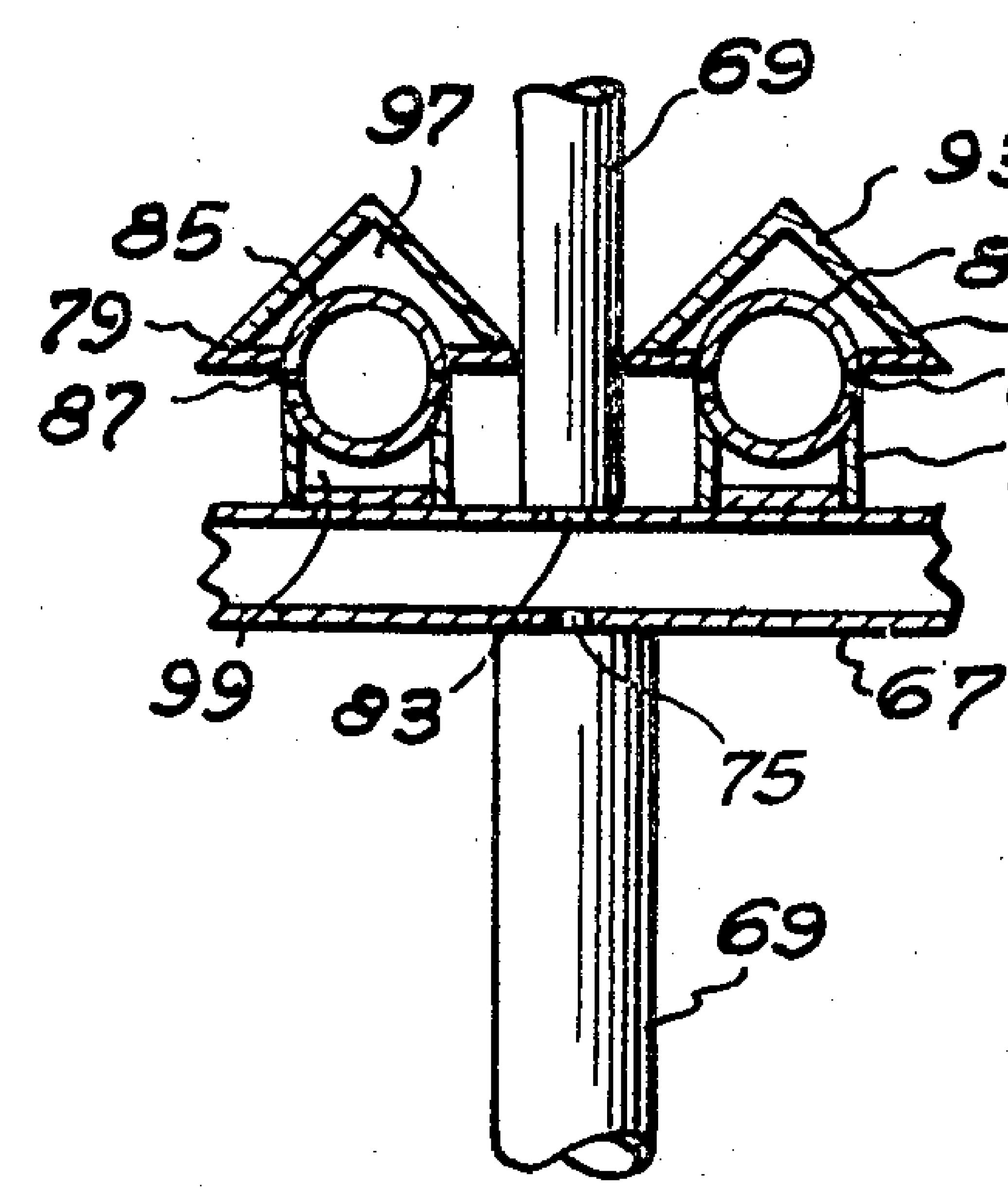

Fig. 6.

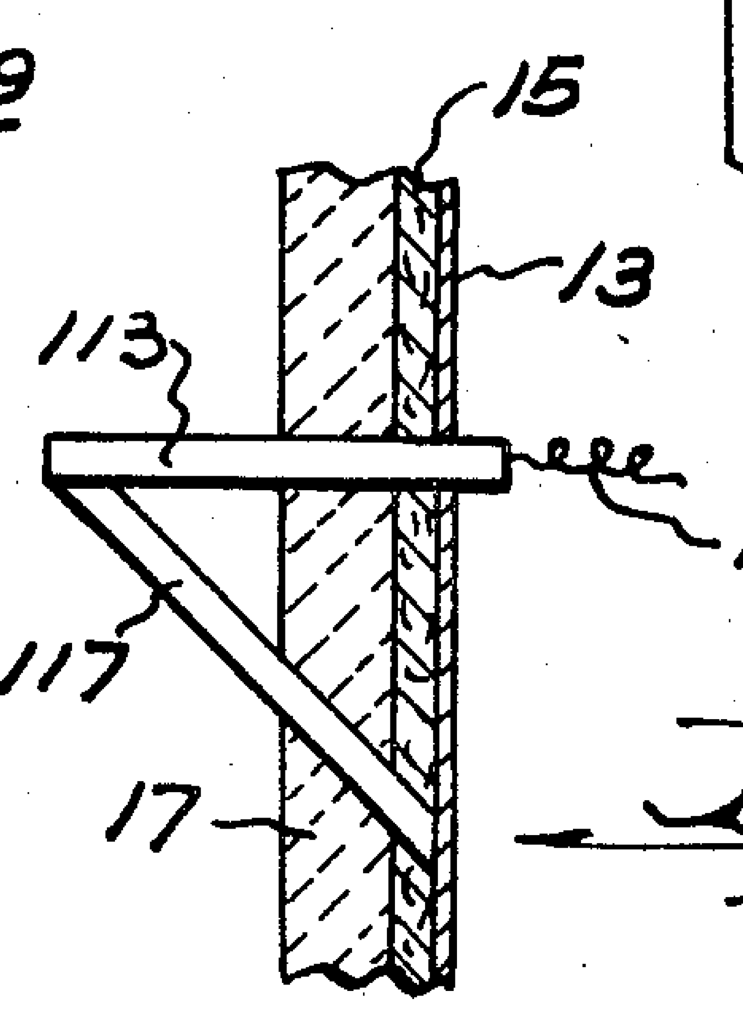

Fig. 5.

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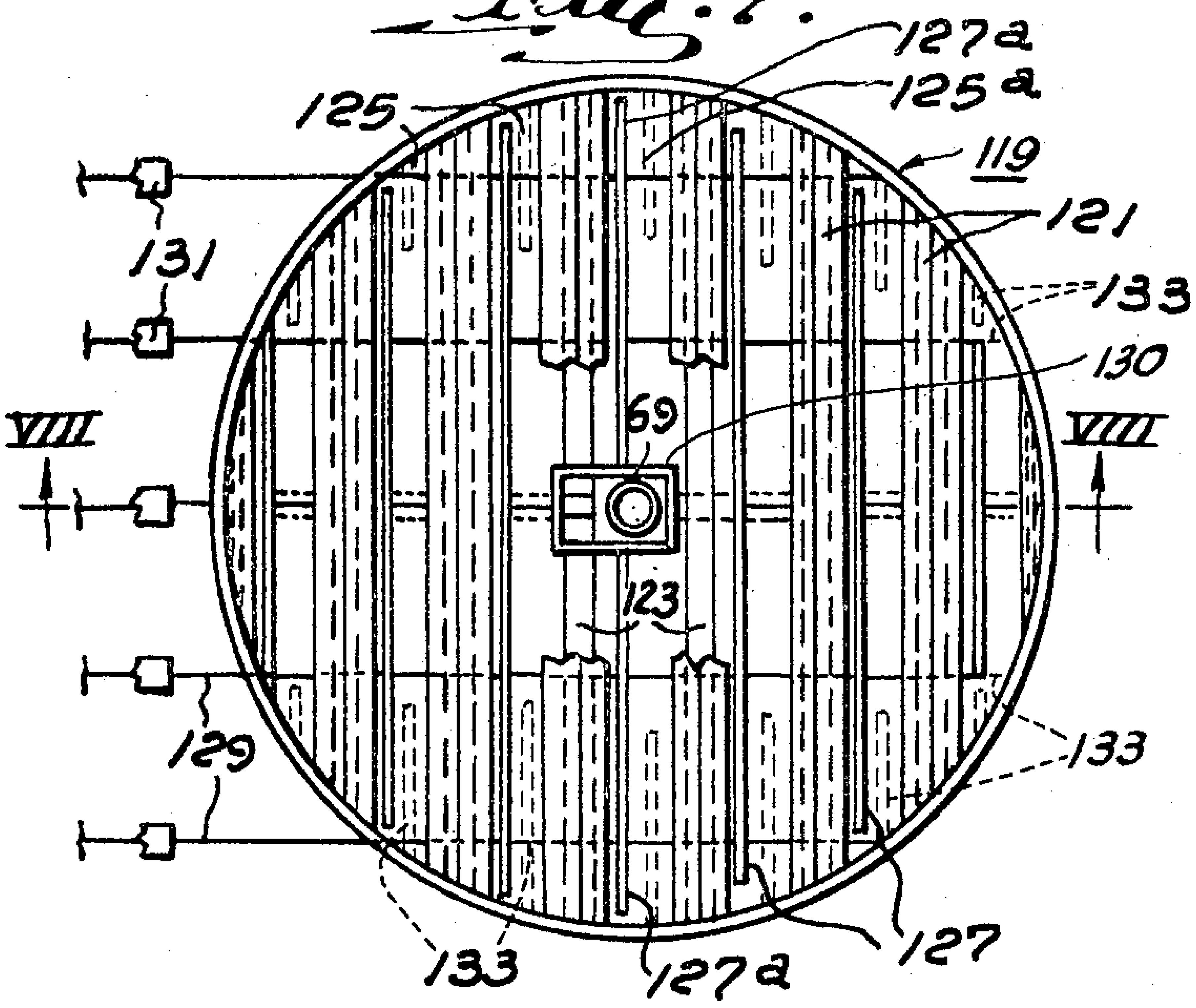
Fig. 7.



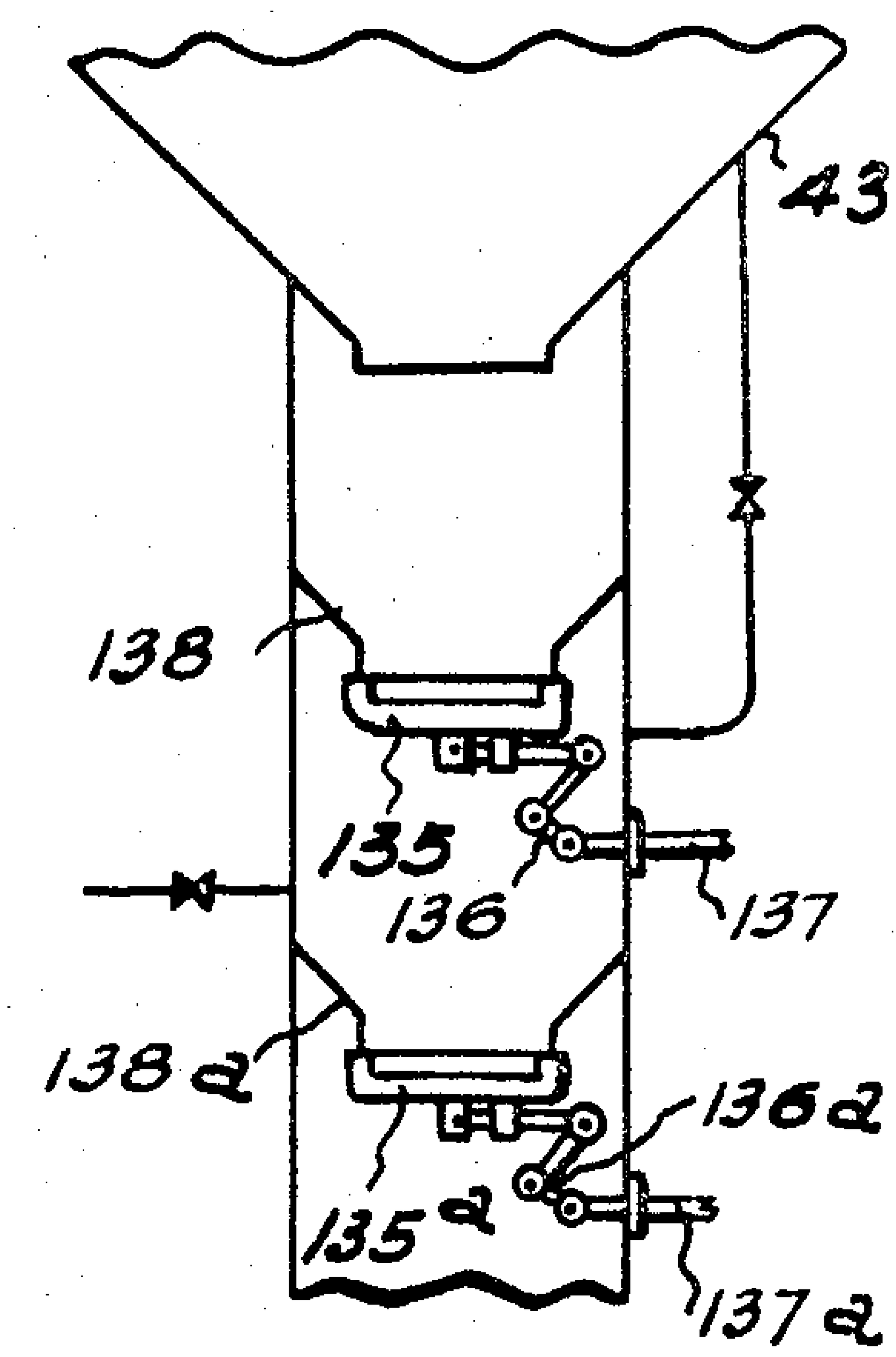


Fig. 9.

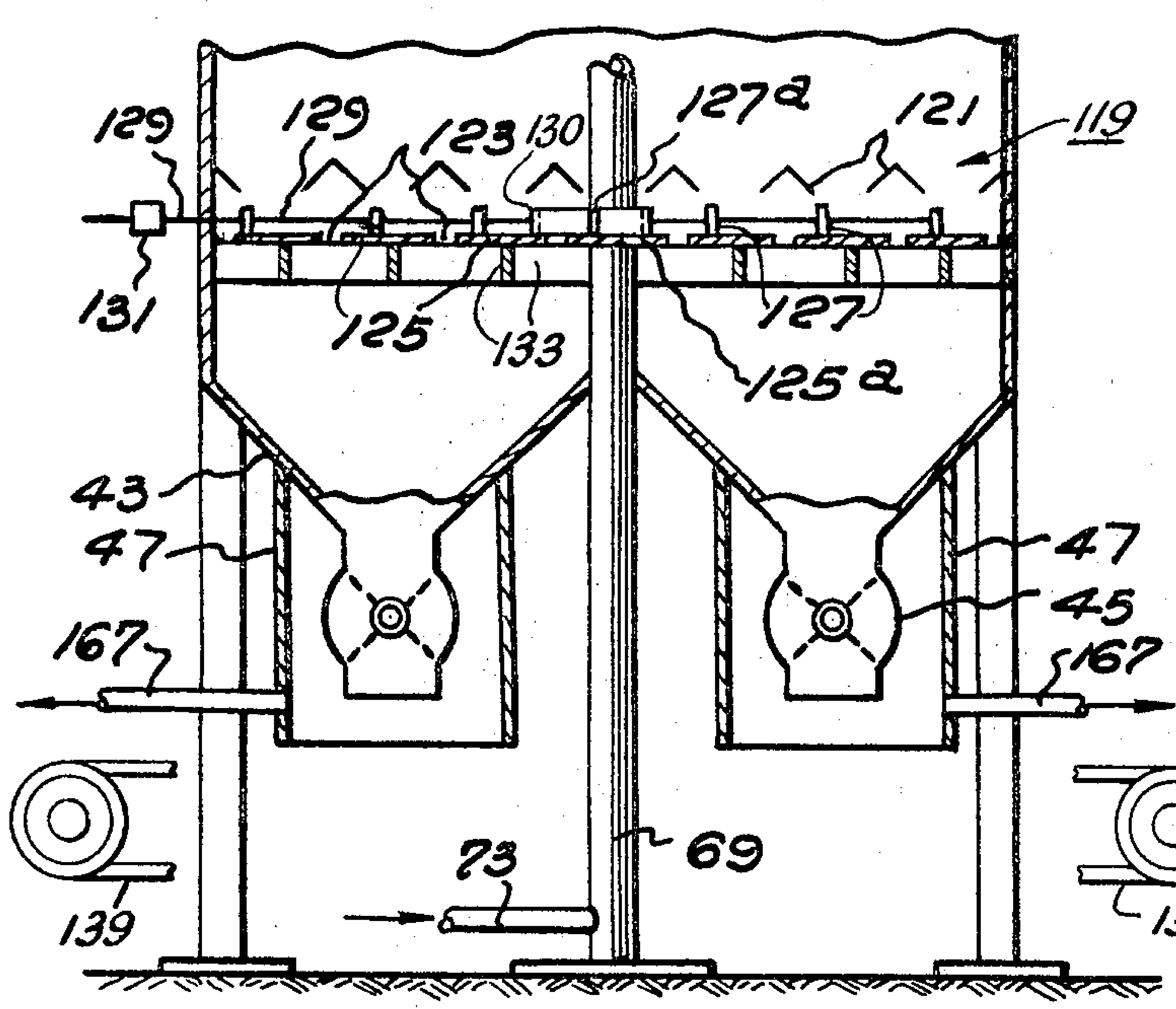


Fig. 8.

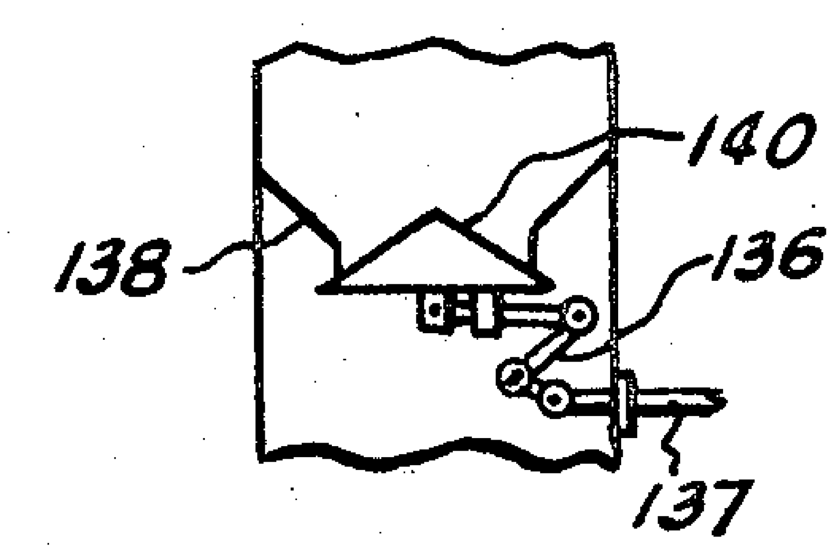


Fig. 9A.

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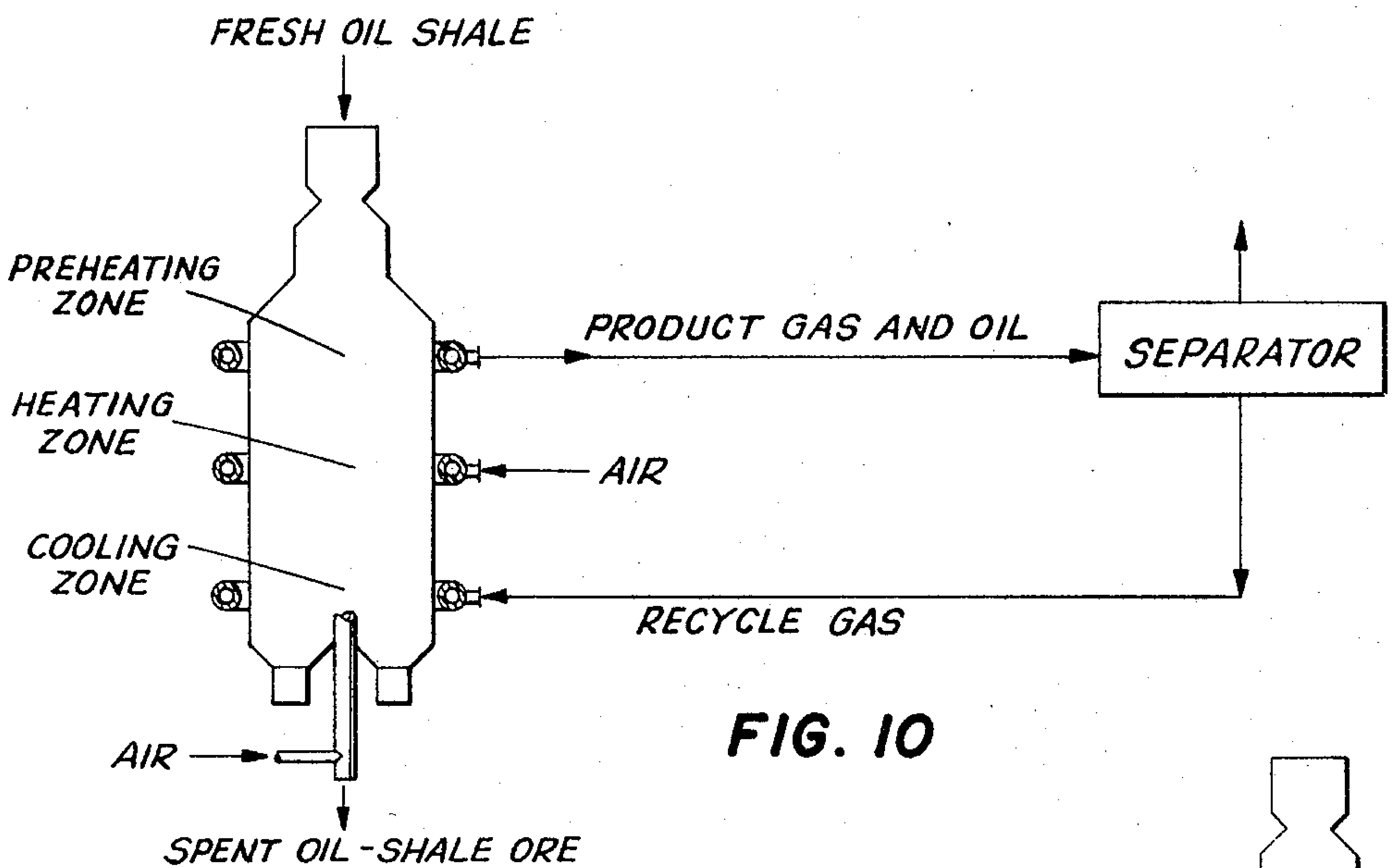

FIG. 10

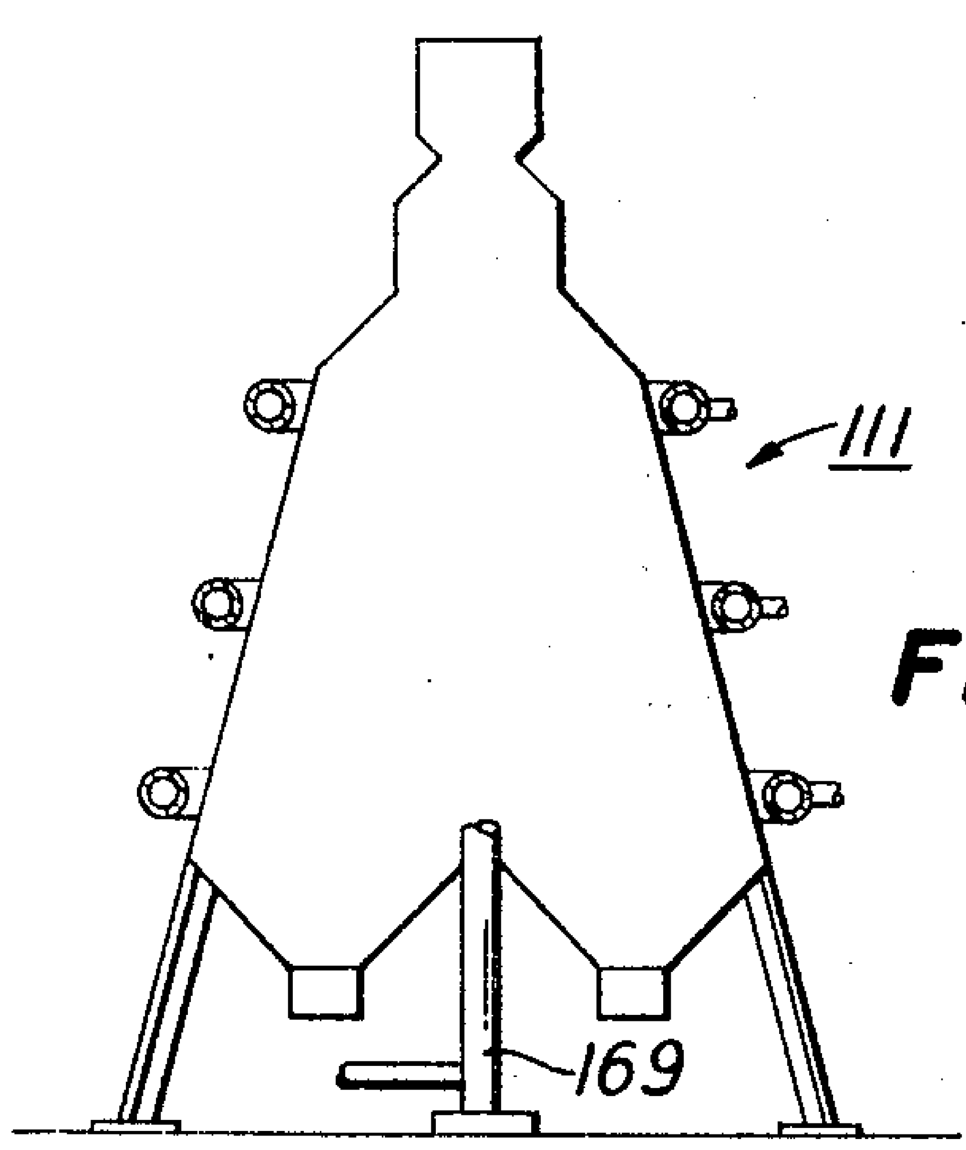

FIG. 11

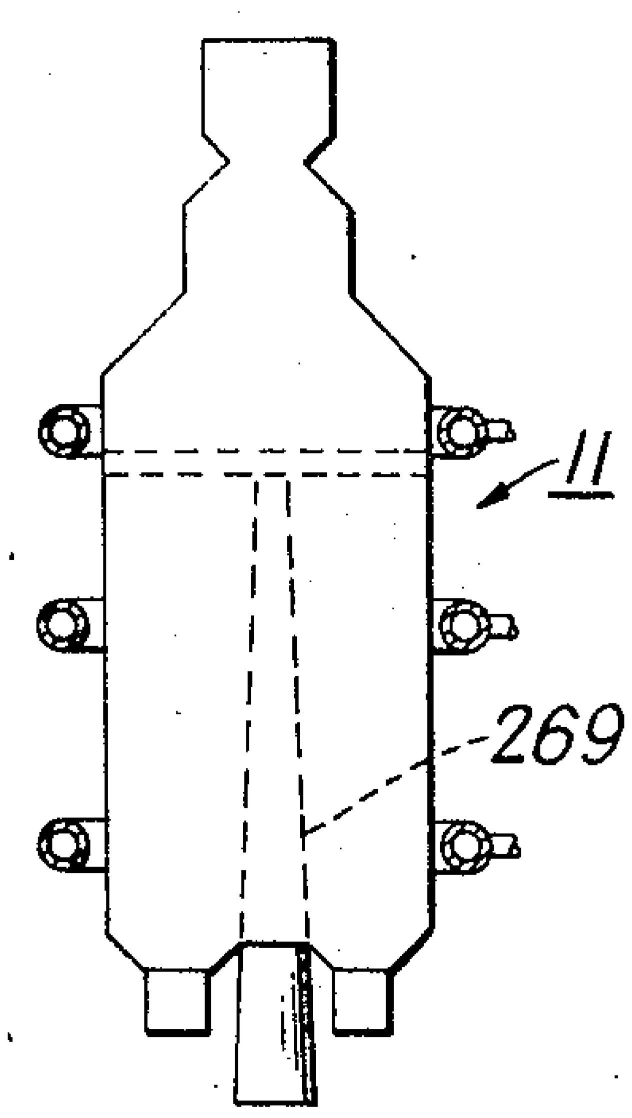

FIG. 12

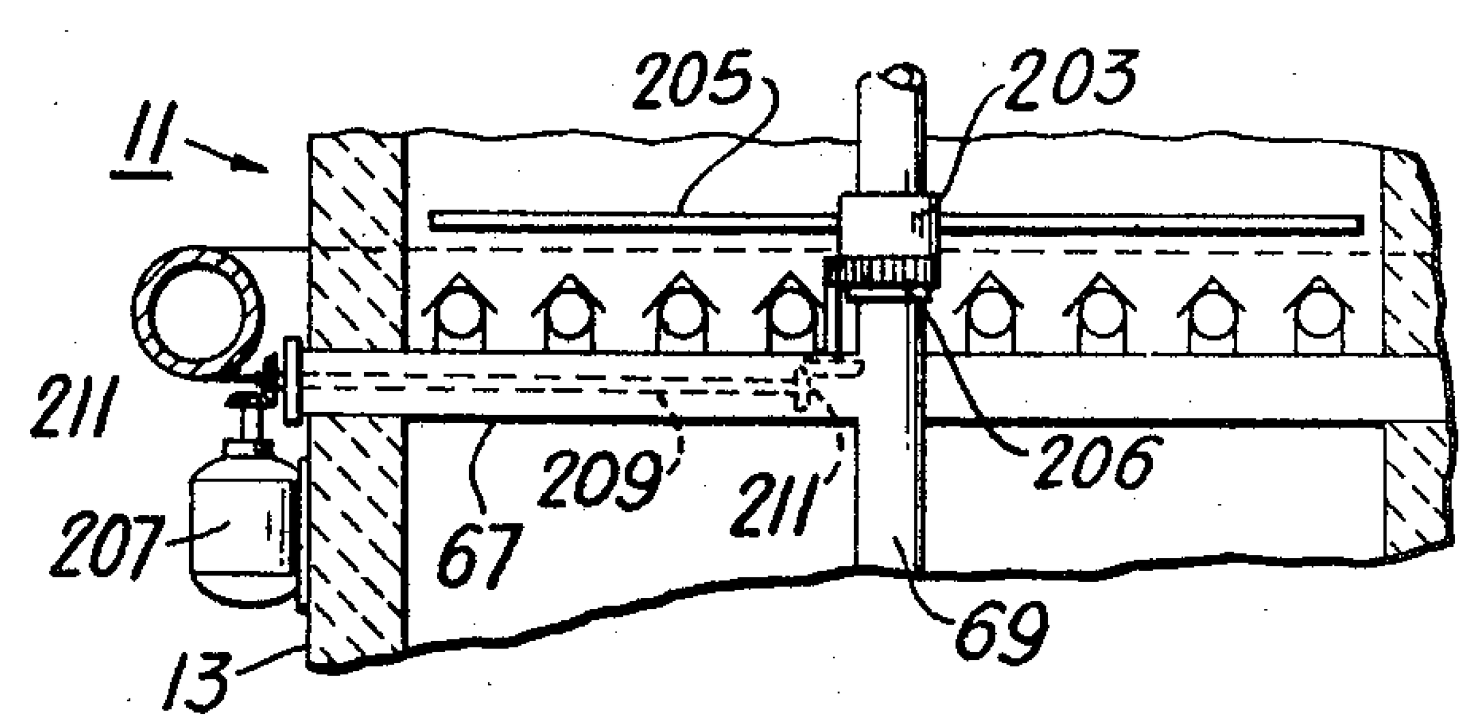

FIG. 13

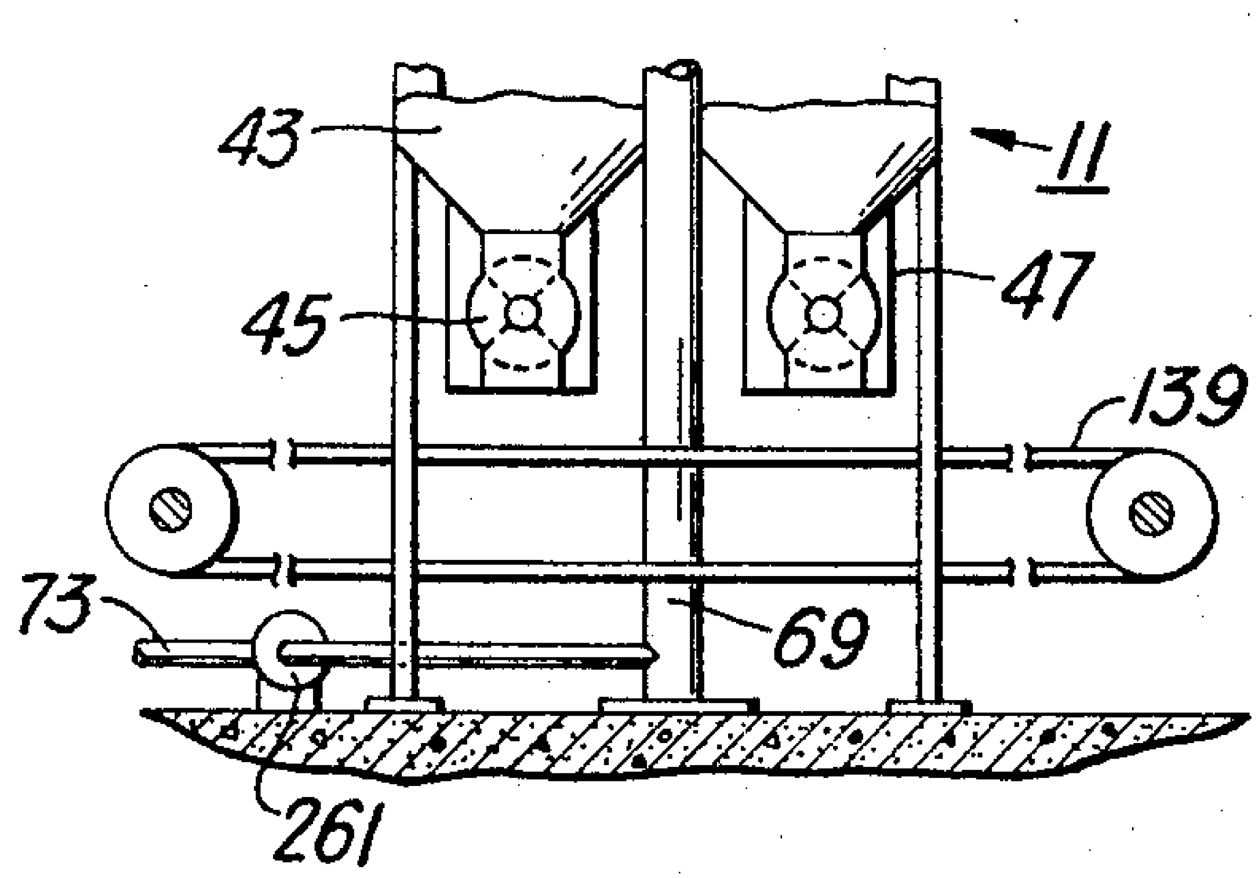

FIG. 14

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APPARATUS FOR RETORTING OIL SHALE HAVING A CENTRAL AXIAL HOLLOW COLUMN

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Int. Cl. C10b *1/04;* C10g *1/00*
U.S. Cl. 202—117 18 Claims

ABSTRACT OF THE DISCLOSURE

Retorting of oil shale ore is carried out in a shaft-type furnace wherein: recycle gas is used to cool the spent oil shale ore in a cooling zone; air is mixed with the recycle gas and the mixture burns in a combustion zone above the cooling zone; and the gaseous products of combustion, including the kerogen derivatives that are driven from the oil shale ore, are removed from adjacent the top of the shaft furnace. The temperature within the retort furnace is controlled by apparatus within carefully defined limits. The gases and kerogen derivatives removed from the retort are separated and the combustible portion of gases, as recycle fuel gas, is fed back into the retort.

BACKGROUND OF THE INVENTION

This invention relates to furnaces and, more particularly, to apparatus and the process for retorting oil shale, using vertical retort furnaces.

In many areas throughout the world, large quantities of oil shale are found. Oil shale is a form of marl that contans a bituminous material called kerogen. Kerogen varies in composition, consisting of approximately by weight 77–83% carbon, 5–10% hydrogen, 10–15% oxygen and a small percentage of nitrogen. When the oil shale is heated, the kerogen is decomposed into derivatives such as oil, gas and other acidic and basic compounds.

Vertical shaft furnaces have been used heretofore to destructively distill the kerogen of the oil shale to obtain the valuable oils, gases, and other acidic and basic compounds. But, the equivalent available heretofore has not been suited to the efficient destructive distillation of the large quantities of oil shale ore that are necessary to make the recovery process economical. The present invention discloses apparatus that makes the destructive distillation of kerogen from oil shale ore economical and practical.

SUMMARY OF THE INVENTION

According to the invention the temperatures at various vertically separated levels in an oil shale retorting furnace are monitored by temperature sensing instruments. A temperature profile controller correlates the temperature data, controls the flow of fuel gas and air into the furnace, and the rate of removal of the derivatives of kerogen driven off from the oil shale ore. Thus, the level of the raw oil shale ore moves downwardly and uniformly within the retort furnace and maximum recovery of liquid derivatives from the kerogen is achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a schematic arrangement of an embodiment

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of the apparatus suitable for obtaining oil and gas from oil shale;

FIG. 2 is a detail of the top portion of the apparatus of FIG. 1;

FIG. 3 is a cross-sectional view of the gas take-off shown in FIG. 1;

FIG. 3A is a cross-sectional view of another embodiment of the gas take-off shown in FIG. 3;

FIG. 4 is an elevational view with sections broken out of a temperature sensor such as shown in FIG. 1;

FIG. 4A is an elevational view with sections broken out of another embodiment of the temperature sensor of FIG. 4;

FIG. 5 is an elevational view of another temperature sensor shown in FIG. 1;

FIG. 6 is a cross-sectional view of an air distributor shown in FIG. 1;

FIG. 7 is a sectional view along line VII—VII of FIG. 1;

FIG. 8 is a sectional view (in elevation) along line VIII—VIII of FIG. 7; and

FIG. 9 is an elevational view of another embodiment of the discharge structure of FIG. 8;

FIG. 9A is an elevational view of another embodiment of the structure of FIG. 9;

FIG. 10 is a simplified flow diagram for the furnace arrangement of FIG. 1;

FIG. 11 is a schematic sectional elevation of an embodiment of the furnace of the invention;

FIG. 12 is a vertical elevation of the furnace of FIG. 1 incorporating another embodiment of the support column;

FIG. 13 is a vertical sectional view of a portion of an embodiment of the furnace; and

FIG. 14 illustrates portions of the figures with the addition of an ultrasonic generator.

DETAILED DESCRIPTION

FIG. 10 illustrates generally the process for decomposing the kerogen of oil shale to strip the resulting oil and gas from the oil shale particles. The raw oil shale which has been crushed and sized is fed into the top of a vertical kiln. The oil shale passes downwardly through a preheating zone where it is heated by the gases and vapors passing upwardly through the zone. Then the oil shale passes into a heating zone where the kerogen is decomposed and the gases and vapors released. The gases and vapors flow upwardly but oil shale, now the spent shale, continues downwardly and is removed at the bottom of the vertical shaft. Incoming recycle gases pass through the spent oil shale as the shale travels downwardly through a cooling zone where the shale is cooled and the recycle gases are heated.

The oil vapors and gases are removed at the top of the kiln near the location where the raw oil shale is fed into the kiln. The liquid and gaseous components are separated outside of the kiln. Some of the gases are recycled to the cooling zone of the kiln where the recycled gases are heated as they pass upwardly through the kiln and are burned at the heating zone to provide the heat to drive a further quantity of oil and gas from the oil shale.

The novel apparatus for obtaining product oil and gas by the destructive distillation of oil shale comprises generally a vertically elongated retort furnace **11**, oil shale feed means **23** for introducing oil shale into the upper end of said furnace, product removal means **53**, **55** for removing product oil and gas from the upper end of said furnace, means **89**, **79** for introducing air to burn fuel gas introduced into the furnace at **101**, **81** to supply the heat for said destructive distillation, a column **69** extending generally axially of said furnace for supporting in part selected ones of the foregoing means, and a grate **119** near the bottom of said furnace for controlling the discharge of oil shale from the furnace.

Referring to FIG. 1, apparatus suitable for carrying into practice the method of the invention includes a retorting furnace **11** having a cylindrical steel outer shell **13** which is lined (FIG. 5) with a first inner layer of compressible insulating material **15**, preferably in block form and a second and innermost layer **17** of refractory material, in the form of bricks or cast refractory (FIG. 5). The top end **19** of the metallic outer shell **13** is frusto-conical in shape, and is also lined in the same manner as the main cylindrical shell **13**. The frusto-conical top **19** merges with a cylindrical skirt portion **21** of a bell housing **23**. The lower end of the outer shell **13** terminates in four frusto-conical members **43**, each of which connects to a conventional rotary vane feeder mechanism **45**. Around each rotary vane feeder **45** is a skirt **47** which is connected to the sloping side wall of the frusto-conical member **43** and which is open at the bottom.

The fresh or raw oil shale is introduced into the top of the furnace near the locus of removal of the valuable vapors and gases that have been produced in the kiln. Bell **23** enables the raw oil shale to be introduced into the top of the furnace without losing these valuable by-products. Within the bell housing **23** are upper **25** and lower **27** conical bells that cooperate with upper **29** and lower **31** cones respectively to seal upper **33** and lower **35** material receiving chambers within the bell housing **23**. The upper **25** and lower **27** bells are movable vertically by means of control rods **37**, **39** respectively, whereby oil shale ore in the upper chamber **33** gravitates into the lower chamber **35** when the upper bell **25** is lowered away from the upper cone **29**, and the lower bell **27** is in the closed position.

Prepared oil shale ore is fed to the upper chamber **33** from a conveyor belt **41** or other suitable materials handling apparatus, which may be operated in a coordinated manner with other apparatus of the system so that at least one of the ore receiving chambers **33**, **35** is full of oil shale ore at all times.

So that the flow of oil shale particles will be uniform from the start of the flow of particles through the furnace, a plurality of coaxially disposed louver rings are arranged in circumferential echelon at the top of the furnace **11**, within the frusto-conical top portion **19**. In the illustrated embodiment of the invention, two such rings **49**, **49*a*** are shown (the upper ring **49*a*** being smaller in diameter than the lower ring **49**) but more than the two rings may be used, if desired. Such rings **49**, **49*a*** are held in fixed relation by brackets **51** attached to the inside of the frusto-conical shell **19**. The rings are spaced apart both radially and vertically in such a way that the shale ore stock line in the frusto-conical portion **19** is spaced apart from the refractory **17**. Since a gradient of particle sizes may exist, this arrangement of the louver rings **49**, **49*a*** keeps the larger pieces of shale ore from gravitating downwardly and outwardly so as to lie against the lining **17** of the furnace. Should the larger pieces of oil shale ore collect against the lining **17**, most of the gases which supply the heat would tend to flow through the larger pieces of shale ore adjacent the furnace lining and a lesser amount of gases would flow through the more densely arranged smaller particles in the central region of the furnace. In this invention the flow tends to be uniform.

The gases and oil vapors which have evolved from the kerogen in the oil shale are removed at a location near the introduction of the raw oil shale. The gases and oil vapors thus in ascending in the furnace give up their heat to and thus preheat the oil shale which is descending. Accordingly, surrounding the top of the cylindrical shell **13**, in spaced apart relation, is a manifold conduit **53** which is connected in communication with a plurality of spaced apart parallel horizontal gas off-takes **55**. Each off-take **55** is a U-shaped member (FIG. 3) having a rounded top and an open bottom. The U-shaped member **55** is supported in the refractory walls **15**, **17**. A flat bottom closure member **57** within the refractory lining **15**, **17**, extends outwardly of the shell **13** to join manifold **53**, as indicated generally in FIG. 2, to prevent loss of the valuable gases and vapors to the atmosphere.

The gas off-takes **55** (FIG. 3) are advantageously so constructed that the ratio of height, H, to width, W, is not greater than five to one, and is preferably not less than one to two. The width, W, of each off-take, in a preferred embodiment of the invention, should not be greater than twelve inches in order to minimize the void space below the off-take, and to reduce the effect of segregation that may take place as the particles flow around the lower edges of the off-take. The distance between the walls of adjacent off-takes in a preferred embodiment should not exceed three feet for the reason that, when the shale ore gravitates around the off-take **55**, the void space below the bottom edges of the off-take **55** may contain mostly the coarser particles of the shale ore, wherefore there will be a flow path of lesser resistance for the hot gases, and an uneven distribution of heat throughout the shale ore bed results. Further, a spacing that is not greater than three feet is desired to maintain a uniform flow pattern of gases into the off-takes **55**.

The manifold **53**, in a preferred embodiment of the invention, will be of such size that the static pressure difference between diametrically opposite locations on the manifold will be not greater than six inches measured by a water column.

FIG. 3A illustrates the cross-sectional shape of another embodiment of an off-take **59**; it being formed of spaced parallel side plates **61** with vaulted caps **63**, **63*a*** at the top that are maintained in spaced apart relation by spacers **65**. The space between the vaulted caps **63**, **63*a*** is used to conduct either a cooling gaseous fluid, such as air, or a cooling liquid, such as water.

While bell **23** feeds the charged fresh oil shale into furnace **11** incrementally, the increments can be so spaced as to maintain an almost constant supply of fresh oil shale at the entrance to the furnace, thereby providing a substantially continuous flow of oil shale down the furnace to maintain the furnace in a steady-state condition. Louvres **49** tend to keep the charge uniform as it starts the movement down the furnace. The rounded tops of the off-takes **55** decrease resistance to the flow of oil shale downwardly through the furnace, and the open bottoms decrease resistance of the gas to exhaustion from the furnace. In this manner, the charge can be fed into the top of the furnace without loss of valuable vapors and gases, the sensible heat can be extracted insofar as is practical from the by-product gases and vapors as quantities of heat to preheat the fresh shale oil, and the temperature difference between the gases and the oil shale is maintained at a minimum to give greater thermodynamic efficiency to the furnace.

From FIG. 2 it will be noticed that the plurality of gas off-takes **55** are centrally supported on a hollow rectangular horizontal support member **67**. The top wall of the support member **67** is flat in way of each off-take **55**, and supports an inverted angle-shaped cap **77** that extends between the walls of adjacent gas off-takes **55**. This cap prevents shale ore from resting and accumulating on the top flat wall of the member **67**.

The ends of support member **67** are mounted in the refractory lining **15**, **17** and project outwardly beyond the furnace shell **13**. Support member **67** is also supported near its mid length location by a hollow vertical conduit columnar member **69** that extends below the bottom of the furnace **11** and is supported upon a suitable foundation **71** (FIG. 1). The lower end of the vertical conduit member **69** communicates with a conduit **73** that conducts coolant, such as air, steam and the like, into the vertical conduit member **69**. The gaseous coolant flows from conduit **73** through the hollow of vertical conduit member **69** into the horizontal support member **67** and through holes **75** (FIG. 2) in the bottom wall of the member **67** in the furnace. The coolant gases also flow through the horizontal member **67** to the ambient atmosphere outside of the furnace **11**. Thus, flexibility is achieved in control of the temperature at the top of the furnace.

Between the bottom and top of the furnace **11** are air distributors **79** and fuel gas distributors **81**. Each of these distributors is in its own bank in separate horizontal planes. The banks are comprised of a plurality of parallel ducts extending across the furnace. The respective air and fuel distributors **79, 81** are disposed in vertical spaced apart relation, with the air distributors **79** being located above the fuel distributors **81**. Each bank of distributors **79, 81** is also supported near their mid length location by a horizontal hollow support member **67**, which is mounted in the refractory walls **15, 17** and extends transversely of the furnace **11**, as mentioned hereinbefore. The support member **67**, as described before, is also supported near its mid length portion by the central vertical member **69**, and is in fluid communication with the central vertical conduit member **69** through hole **75** in the lower wall of the conduit **67**. The upper wall of conduit **67** has a hole **83** to admit cooling fluid to flow upward in the portion of the vertical member **69** extending above the conduit **67**.

FIG. 6 illustrates a preferred form of horizontal air distributor **79**. Each distributor comprises a horizontal cylindrical tubular conduit **85** having a plurality of diametrically opposed, horizontally spaced apart holes or orifices **87**. Each conduit **85** communicates with an air manifold **89** which annularly surrounds the outer shell **13** of the furnace. Air under pressure is provided to manifold **89** from a suitable source such as a fan **91**.

The area of the distributors **79, 81** is such that the pressure differential between opposed ends thereof is minimized; preferably, this pressure difference will not exceed 6 inches as measured by a water column.

The air conduit **85** is fitted with a vaulted cover **93** (FIG. 6) that is welded to, or otherwise fluid tightly affixed to, the upper portion of conduit **85**, and a box-type lower trough **95** that is fluid-tightly connected to the lower portion of the conduit **85**. The upper vaulted cover **93** extends outwardly far enough so that the shale ore, because of its angle of repose, cannot obstruct the openings **87** in the conduit **85**, and thereby obstruct the flow of gas from the distributors. The cover **93** forms with the conduit **85** a conduit **97** for cooling fluid, and the lower box-like trough **95** also forms a conduit **99** for cooling fluid. Both of the passages **97, 99** allow for the flow of a coolant such as air or water to cool the conduit **85**. The cover and trough also strengthen the horizontal conduit **85**, especially when it becomes heated while in service.

The fuel distributors **81** (FIG. 1) are generally of the same type as the air distributors **79**. Since the fuel distributors are in the cooling zone of the furnace where temperatures are not as high as in the heating zone, cooling passages, such as **97, 99** of distributors **79** and the structural features that create these cooling passages may be omitted if desired. The distributors **81** are arranged in spaced apart horizontal rows, and each distributor **81** communicates with an annular fuel manifold **101** that encircles the lower portion of the funrace **11**.

As described in the foregoing, a large number of parameters are present for the control of the pyrolysis of the oil shale as the oil shale proceeds down the furnace. Typical parameters, for example, are the flow of fresh oil shale, the rate of take-off of the by-product gas, the rate of addition of cooling gas, the rate of addition of air through the air distributor in the heating zone, and the rate of addition and kind of fuel supplied at the cooling zone. To monitor the conditions occurring within the furnace, temperature measuring instruments are located at various levels within the furnace and at varying radial locations. The temperature in accordance with this invention is regulated and determined at the interior of the furnace. Referring now to FIG. 4, for an embodiment of a temperature measuring instrument for ascertaining the temperature within the furnace a conduit **103** is mounted at one end to the central vertical support column **69**, and is maintained in a horizontal attitude by means of diagonally arranged struts **107**. The outer end **105** of the conduit **103** is closed, and a thermocouple **109**, or other suitable temperature measuring instrument, resides in the conduit **103** near the closed end. Electrical wires **111** lead from the thermocouple **109** into the central vertical column **69** through the horizontal support members **67** and thence out of the furnace to a suitable temperature reading station.

A hole **110** with a removable cap **112** is provided on the central vertical column **69**, in a location diametrically opposite the conduits **103**, and **104** (FIGS. 4, 4A), to service and maintain the thermocouple elements **109, 109*a***.

Alternatively, the temperature measuring unit may comprise a closed end conduit **104** disposed in a downwardly sloping manner from column **69** and maintained in such an attitude by a diagonal strut **107*a***. A thermocouple **109*a*** resides near the end of the conduit **104**, and electrical wires **111*a*** lead from the thermocouple out of the furnace by way of the central column **69** and support member **67**. Temperatures may be also measured at desired distances from the interior of the wall of shell **13** as illustrated at FIG. 5 by a closed end tube **113** which is mounted to the outer shell **13**, and which projects horizontally through the refractory lining **15, 17** into the furnace **11**. A thermocouple (not shown) resides in the tube **113** and electrical leads **115** from the thermocouple are connected in the temperature measuring or read-out equipment. The tube **113** is supported by a diagonal strut **117** in a horizontal attitude; but, of course, it may be supported at any convenient angular attitude in the same manner as tube **103*a***.

The rate at which the oil shale leaves the bottom of the furnace, and indirectly the rate of descent of the shale or residence time of the shale in the furnace is controlled by grate structure **119**. The grate structure **119** (FIGS. 7 and 8) includes a plurality of spaced apart parallel horizontal diverter members **121** which are in the form of inverted structural angles. Each diverter member **121** is located vertically above a gap **123** between adjacent flat bottom support plates **125** that are fixed to shell **13** and arranged in spaced apart relation in a horizontal plane.

Plates **125** are supported by a plurality of vertical mutually perpendicularly arranged plate webs **133** which extend as chords from one side of the furnace shell **13** to the other side. The plate webs **133** form a grid that supports the horizontal plates **125** and the weight of the oil-shale ore in the furnace **11**. The plate webs **133** may, of course, have other desirable shapes such as I-beams, channels, Z-bars and the like. Further, the grid members **133** may be hollow box beams that are fluidly cooled as by air or water.

On each support plate **125** is mounted a movable pusher bar **127** that is rectangular in cross section. Each pusher bar is connected to a plurality of actuating rods or drive shafts **129**, that extend outwardly of the furnace shell **13**, as shown in FIGS. 7 and 8. One of the fixed horizontal plates **125*a***, however, is mounted to the support column **69**, and the pusher bar **127*a*** on that particular support plate **125*a*** is connected to a yoke **130** that surrounds the central vertical column **69**. In this manner, all of the pusher bars operate simultaneously when actuated by power sources, such as by hydraulic cylinders and pistons **131**.

Those skilled in the art will recognize that the showing in FIG. 8 is not to scale, and that the sides of the diverter members **121** slope at such angles that the spent shale ore, having a natural angle of repose, will not dwell on the sloping sides of the diverters **121**. Further, the diverters **121** are so located, with respect to the support plates **125** and pusher bars **127**, that the spent shale ore will not gravitate continually down and around the diverters into the openings **123**. The spent shale ore desirably rests on the bottom support plates **125** and is removed therefrom only by reciprocating the pusher bars **127**, as mentioned hereinbefore.

FIGS. 9 and 9A illustrate other embodiments of apparatus for removing the spent shale ore; that is, the residue material after the kerogen derivative has been driven off as the oil shale ore descends in the furnace. The appaartus of FIG. 9 includes a pair of vertically spaced apart flapper valves or gates **135**, **135***a* that are actuated by link mechanism **136**, **136***a*, powered by push rods **137**, **137***a* connected to a hydraulic cylinder-piston arrangement (not shown) or other suitable power mechanisms. Each flapper valve or gate closes the bottom of a hopper **138**, **138***a* which receives spent shale material in sequential manner; that is, the spent shale material falls from the grate structure **119** (FIG. 8) into the hoppers **138**, **138***a*. The spent shale material collected first in hopper **138** and, periodically, the flapper valve or gate **135** opens to drop the collected spent shale material into hopper **138***a* below. Then, periodically, but not necessarily simultaneously, the lower flapper valve or gate **135***a* opens to drop the collected spent shale material onto a conveyor belt **139**, as shown in FIGS. 1 and 8.

FIG. 9A illustrates another embodiment of flapper valve or gate. In this embodiment, the flapper valve or gate **140** is a conical bell that is similar to the conical bells **25**, **27** of FIG. 1. Such bell valve or gate **140** cooperates with the walls of the hopper **138**, and operates in response to movement of a link mechanism **136** powered by a push rod **137**.

As an example of the operation of the apparatus in accordance with the invention, the conveyor belt **41** (FIG. 1) delivers fresh oil shale ore at a controlled rate of between 2 and 12 tons per day per square foot of cross-sectional area of the furnace **11** into the upper chamber **33** of bell **31**. The oil shale ore then gravitates into the lower chamber **35**, and thence into the furnace proper when the bells **25**, **27** are operated in sequence. Advantageously, the oil shale ore has been comminuted and sized so that the particles have a maximum and minimum size of between 2.0 inches and 0.1 inch.

While the furnace is operating, the gases produced in the retort and resulting from the decomposition of the kerogen are removed from the manifold **53** by way of conduit **143**, a cooler condenser **145**, a gas cleaner (wet or dry type) **147**, and an exhaust fan **141**. A portion of the product gas flows through a flow controller **149** and into the manfold **101** through a conduit **151** as recycle fuel gas.

When desirable, an additional gas cleaner **165** may be connected by a conduit **167** in communication with the skirt **47** around each rotary feeder **45**, to remove any traces of gas that may escape through the rotary feeders. A suction fan **169** communicates through conduit **171** with the gas cleaner **165** and, through a conduit **173**, with an exhaust stack (not shown). Gas flowing in conduit **173** may be bled through conduit **175** and valve **177** into a product gas line **179** connected to the fan **141**. Valve **181** in conduit **179** is automatically actuatable by the temperature profile controller **155** to maintain substantially atmospheric pressure at or adjacent the rotary feeders **45**.

As the oil shale ore descends through the retort **11** at a desired rate, recycle gas (generally between 10,000 and 30,000 s.c.f. per ton of shale ore) flows through the flow controller **149** into the recycle gas manifold **101**. Air is added by the air distributors **79**. However, a deficiency of oxygen is present in the furnace; that is, a smaller quantity of air is present in the furnace than the amount that is theoretically required to consume all of the gas. Sufficient air is added through manifold **89** and distributors **79** to maintain a temperature, immediately above the level of the air distributor **79**, **89**, in the range of 800° F. to 1400° F. Of course, the temperature at localized points in front of the holes **87** of the distributor **85** may exceed 1400° F. As illustrated herein, a tempreature measuring thermocouple **109** is electrically connected to a temperature profile controller **155** that regulates the rate of air flow (preferably in the range of 2000 to 6000 s.c.f. per ton of oil shale ore) through an air control valve **157**A to the manifold **89** and air distributor **79**. To this end, controller **155** regulates the speed of the blower or fan **91** or the opening and closing of air control valve **157***a* or both to maintain the temperature in the retort at the air distributor level **79**, at the desired temperature.

To conserve thermal energy, the sensible heat is recovered from the spent oil shale before the shale leaves the retort. This heat is recovered by flowing the fuel, herein the recycle gas, upwardly through the shale. To accomplish this, a portion of the product gases pass through the flow controller **149** and conduit **151** to manifold **101** and to the recycle gas distributor **81**. This flow is maintained at a rate sufficient to cool the spent shale material leaving the retort to a temperature in the range of 100° F. to 400 F., as measured by the temperature measuring thermocouple in conduit **103***d*, located just below the recycle gas distributors **81**, **101**.

If the spent shale residue leaving the retort is cooler than desired, the temperature measured by the instrument in conduit **103***d* actuates the temperature profile controller **155**. Ratio controller **159***b* responds to a signal from the temperature profile controller **155** to decrease the ratio of gas to air entering the manifold **101** by regulating valve **157***b*. If the temperature at level **103***d* is higher than desired, the temperature profile controller **155** actuates ratio controller **159***b* so that valve **157***b* opens slightly, thereby allowing more recycle gas to enter the manifold **101**. When, on the other hand, it is desired to raise slightly the temperature at level **103***b*, assuming that the temperature at level **103***d* is satisfactory, an adjustment may be made to the temperature profile controller **155** that will cause a slight increase in the rate of flow of air to the manifold **89** for the air distributors **79**; ratio controller **159***a* being actuated to raise the recycle gas flow rate proportionately to maintain the same ratio of gas to air, and, thereby, automatically maintain substantially the same desired temperature at level **103***d*. If the slight change in gas and air flow rates, as related to the controlled shale ore rate passing through the retort, disturbs slightly the desired temperature at level **103***d*, the temperature profile controller **155** in response adjusts the recycle gas to air ratio controller **159***b*. The ratio controller **159***b* then opens or closes slightly the valve **157***b*, without disturbing appreciably the position of ratio controller **159***b*.

If, in any particular instance, the gas is recycled at a rate sufficiently high to cause the recycle gas valve **157***b* to fully open, or open so far that the ratio controller **159***b* becomes partially noncontrolling, then the flow controller **149** may open the flow control valve **161** enough to return the ratio controller **159***b* to a state of active control over the rate of flow to the distributor **81**, **101**. If such maneuvering fails to achieve a stable controlled condition, then the temperature profile controller **155** may increase the speed of the gas recycle exhaust fan **141** to bring the ratio controllers back to a controlling state.

There will be cases where the temperature of the gases leaving gas off-takes **55**, **53**, as measured at level **103***a*, or as measured by a thermocouple-type device **163** in conduit **143**, will be desirably controlled at some maximum temperature. Whenever the temperature, as measured at **103***a*, or at **163**, reaches this maximum value, then the temperature profile controller **155** will activate the ratio controller **159***b* and reset the ratio of recycle gas to air downward slightly.

Temperature profile controller **155** may also be used to regulate the temperature in the cooler-condenser **145** by regulating the rate of flow of cooling medium which may be either water or gas, to the cooler-condenser **145**. Likewise, the temperature profile controller **155** may be used to control the degree of cleanliness of gas leaving the gas cleaner **147** by regulating the pressure differential across the gas cleaner, or by regulating the flow of water to the gas cleaner (when a wet unit is used), or by regulating both the pressure differential and the fluid flow rate.

In accordance with this invention the temperature profiles in the retort **11** for the maximum rate that oil shale ore can be retorted, optimum recovery of shale oil, obtaining optimum release of kerogen from the shale, and a minimum fuel consumption can be determined and the temperature profile controller **155** may be set to maintain the desired temperature profile as measured at various elevations without requiring control by a manual operator.

When desired, a temperature profile controller **155** may be used to maintain the same desired temperature profiles in a number of similar large vertical shaft retorts equipped with similar temperature profile measuring means.

The temperature measuring units described herein provide the needed accuracy for the temperature profile. Heretofore, it has been difficult to obtain temperature measurements within the bed, at the center or axis of the vertical retort or kiln, even for relatively small diameter shaft units. Heretofore when the temperature probe extended horizontally to the axis of the shaft from the shell or periphery of the retort, the pressure exerted on the probe unit, due to the friction and weight of descending solid particles, caused the relatively long probe unit (at the elevated temperatures) to bend downwardly out of the path of the shale and away from the center or axis and accurate temperatures could not be obtained. When the probe did bend down and away from the center or axis of the kiln, it would frequently break off and become inoperative and incapable of being used with a temperature controller to regulate and maintain the temperature of the bed at a particular elevation. Some attempts were made to measure temperatures within the bed, near the center or axis of the retort, by suspending a very long probe tube down into the bed from the top of the retort; but the long protective probe tube, extending from between the top of the retort and about midway between the top and bottom of the shale bed, became badly distorted and bent due to various pressures exerted against it by the descending solid particles so that it was not known definitely what temperature was being measured at that particular elevation in the bed.

In accordance with this invention a protector tube **113** (FIG. 5) removes the measuring means sufficiently away from the lining of the retort at a preselected level or zone to indicate the temperatures near to, but not at, the lining. It provides a mean temperature measurement between the temperature profile near the axis of the shaft and the temperature profile near the lining, at a particular horizontal level in the shale bed. Thus in the invention, the temperature in the cross-sectional area of the retort, particularly at the elevation where liberation of shale oils and shale gases is taking place, is maintained at the desired temperature where the effective liberation of the oils and gases takes place. For example, if the temperature near the lining was about 800° F., while the temperature near the center or axis was about 1000° F., effective liberation of the oils does not occur near the lining. Then, the temperature profile controller **155** may be readjusted to raise the temperature at that elevation from 1000° F. to 1100° F., which would also cause the temperature near the lining to rise by approximately an equal amount, i.e., from about the 800° F. to about 900° F. Such temperature near the lining would effect efficient liberation of the shale oils and gases without producing temperatures near the center that result in excessive undesirable cracking of valuable shale oils into decomposition gases.

Likewise, if the temperature at level **103***b* accidentally or by choice reached 2000° F., where a large percentage of the liberated shale oils become cracked to shale gases, and where the bed at this point might be approaching the temperature at which undesired clinker or fusion of shale occurs, then, the temperature measuring means **113** also indicates a temperature that approaches, but probably does not quite reach the same temperature. The temperature measuring means **113** would indicate that dangerously high temperatures prevailed at this elevation, and another measuring means **103***b* at this elevation would confirm the accuracy of the first measuring means **113**. The temperature profile controller could then be adjusted to lower the temperature at this elevation to within the desirable range, that is, between about 800° F. and 1400° F.

When the recycle gases, rising through the retort **11**, reach the distributors **79**, the gases contact air issuing from orifices **87** (FIG. 6) and mix at temperatures that are above the ignition temperature of the gases. In fact, the temperatures at openings **87**, as well as the temperatures in the voids between pieces of shale and in areas between and immediately above the air distributors **79**, must remain above between about 1100° F. and 1300° F., until the oxygen in the air entering the bed through orifices **87** has been consumed to form CO_2 and H_2O. Immediately above the elevation where the ignition has taken place, the average temperature then drops back to the preferred temperature of between about 800° F. and 1400° F.

When a large retort is started up from a cold state, cold oil shale ore may be added to the retort up to an elevation at or slightly above the air distributors **79**. Auxiliary burners (not normally used after the unit is operating and not shown here) may be inserted into spaces (not shown) below air distributors **79** and ignited, burning start-up gas such as natural gas and air, thereby obtaining substantially complete combustion of this auxiliary gas. The precaution should be taken, however, to burn only enough gas at these points so that the temperature at this level is above the ignition temperature of between about 1100° F. and about 1300° F., and below the shale fusion temperature of between about 2000° F. and 2200° F.

Before the temperatures of the oil shale ore at these elevations reach the fusion temperatures, the filling of the remainder of the retort may be resumed. Almost simultaneously, the flow of recycle gas from storage through distributors **81**, and the flow of air through distributors **79** at specified ratios and rates will be started. When these recycle gases, from recycle gas distributors **81** and air distributors **79** meet and mix at and adjacent the air distributors **79** and begin to burn at temperatures above the ignition temperature of the gases, the auxiliary start-up burners referred to herein may be turned off (and removed if desired) and combustion will be sustained by the normal recycle gas-air mixture.

If, in controlling the temperature at level **103***b* at between about 800° F. and 1400° F., the temperature of the shale ore should begin to approach between about 2000° F. and about 2200° F., where fusion of shale ore particles into small clumps begins to occur, such a condition is indicated by the presence of clumps in the spent shale ore discharging from the bottom of the retort. Then, the flame temperature should be lowered sufficiently to eliminate this fusion of shale by adding continuously and uniformly an inert gas to the air stream entering the retort through air distributors **79**; being careful, however, always to maintain the temperature at this level above the ignition temperature of the air-gas mixture. This inert gas may be, for example, nitrogen, steam, products of combustion of the recycle gas, or a combination of these gases. The inert gas may be added continuously through a valve **183** in a conduit **185** connected to a source of supply. The valve **183** is actuated by the temperature profile controller, or other controller (not shown) to regulate the ratio of the flow of inert gas flowing through valve **183** to the flow of air flowing through valve **157***a*, thereby maintaining a desired flame temperature at the distributor **79**.

The air and gases issuing from distributors **79** and **81** travel some vertical distance before they become uniformly distributed across the whole cross-sectional area of the retort. For this reason, the vertical distances between air and gas distributors **79**, **81** and between air distributors **79** and the product off-takes **55** must be sufficient for uniformly distributing the gases. In the preferred embodiment, the distance between the distributors **79** and **81** and also between distributors **79** and gas and oil off-takes **55** is at least five feet and, preferably, more than ten feet.

As illustrated herein (FIG. 1) a wet or dry gas cleaner **147** is located in the recycle gas line between cooler-condenser **145** and exhauster **141**; but should gum-like deposits be produced in exhauster **141** to interfere with exhauster operation, wet or dry gas cleaner **147** may be located downstream or on the discharge side of exhauster **141**. Then, the light shale oils, not totally removed in the cooler-condenser **145** (present as a fog in the gas) act as a lubricant in the exhauster **141** and prevent gum (or the like) deposits in the exhauster. When the exhauster is of the centrifugal type, a large percentage of oil particles are removed centrifugally from the gas at the exhauster. Sometimes, this secondary cleaning in the exhauster is sufficient so that the wet or dry cleaner is not needed.

It is preferred to operate the flow measuring and controlling device **159***b* in the recycle gas line under substantially constant pressure. This may be accomplished by controlling the pressure between valves **157***b* and **161** with a pressure controller (not shown).

Where water is scarce, it is possible to cool and condense vapors in the cooler-condenser **145** indirectly. This is done by sectionalizing the cooler-condenser **145**, with the inlet or first section of the condenser-cooler partially cooling the recycle gas using air, and with the air that is preheated in the partial cooling process being used as the air needed at the distributors **79**. Recirculated, cooled water may then be circulated through the outlet or downstream section of cooler-condenser to further cool the gas sufficiently (and preferably to below 175° F.) to obtain desired low power or steam consumption at exhauster **141**.

The apparatus may be operated through a range of pressures. For example, sufficient negative pressure may be carried at the top of retort **11** to maintain substantially atmospheric pressure continously inside of the retort, at the rotary discharge feeders **45** to minimize leakage of gas into or out from the retort. On the other hand, the discharge mechanisms **45** may be maintained tightly sealed, and the whole retort may be maintained at super atmospheric pressure with the top of the retort being maintained sufficiently above atmospheric pressure to prevent accidential leakage of air into the retort at the shale ore feed mechnisms **25**, **27**. Super atmospheric pressures, of course, eliminate the chance of an explosion, due to leakage of air into retort either via the green shale ore feeders at the top or the spent shale residue feeders at the bottom.

Grate mechanism **119** should be at a sufficient distance below the level of the recycle gas distributors **81** so as not to distrub the uniform descent of shale particles across the area of retort until the shale material has descended below the recycle gas distributor **81**. On the other hand, grate mechanism **119** should be located close to the recycle gas distributors to reduce the retort height. The distance between the grate mechanism **119** and distributors **81** usually will not exceed ten feet and, preferably, will be less than five feet.

In accordance with this invention, the use of the central column member, such as the member designated **69** in FIG. 1, permits flexibility in the design of the retort furnace in order to obtain maximum efficiency of operation. For example, when the gas flows are such that conical design of retort is desirable, a retort **111** can be readily made of a frusto-conical configuration such, for example, as illustrated in FIG. 11. The central vertical column **169** itself may be cylindrical, as the column **69** illustrated in FIG. 1 and have substantially the same cross-sectional area throughout the unit or it may have a varying cross section as in FIG. 12. In this instance, the column **269** may be frusto-conical in shape, as illustrated.

As has been discussed before, the hottest portion of the furnace is that portion immediately adjacent the air distributors **79**, because the gas which has been preheated on its path from distributors **81** upwardly through the shale ignites and burns at this zone. Should this temperature rise to the shale fusion temperature, it is possible that some shale will agglomerate and bridge the distributors. Such fusion may cause a condition known as "hang-up" where the shale stops moving downwardly through the furnace and becomes lodged in the upper portion of the furnace **11**.

In accordance with the embodiment of the invention illustrated in FIG. 13, a sleeve **203** with projecting arms **205** is supported by a collar **206** fixed to and surrounding the central vertical member **69**. A motor **207** is secured to the outside of the shell **13** of the furnace **11** and, by way of both a drive shaft **209** extending through the support **67** and suitable gear arrangement **211**, rotates the sleeve **203** and arms **205** in the furnace **11** to overcome any "hang-up" in the furnace.

As illustrated in FIG. 14, ultrasonic vibrations may be used, in conjunction with this furnace, to aid the uniform downward flow of oil shale ore and the escape of the product gas and vapors from the oil shale ore. A simple way of providing ultrasonic vibrations to the interior of the furnace is illustrated in FIG. 14 where a siren **261** is installed in the air inlet **73** which provides cooling air to the furnace. As the air passes through the vanes of the siren **261**, for example, the flow of air is changed to small increments of force of ultrasonic frequency which increments or puffs upwardly through the central column **69** as impact ultrasonic vibrations and thus, to the mass of oil shale in the interior of the furnace.

Those skilled in the art will be aware of the necessity of providing sufficient slope to the walls so that the spent oil-shale ore will always descend into the feeders **45** and will not bridge or repose on the walls **43**, and, thereby, clog the outlet of the retort furnace. In order to facilitate removal of the spent oil-shale ore, and in order to reduce the overall height of the retort furnace, a plurality of feeders are used, as suggested in the drawings. In some applications, however, only one discharge feeder may be used if preferred.

In some instances, a sensing device, not shown, may be installed on the wall **43** to detect the presence thereof of spent oil-shale ore build-up, and a signal from such sensing device may be directed to a controller governing the speed of the feeders **45** whereby they operate at a faster rate to remove the ore build-up.

The grate discharge mechanism **119** at the bottom of the retort furnace oscillates and is controlled by regulator **187** (FIG. 2), so that spent oil-shale ore discharges at such a rate (either increasingly or decreasingly in controlled stepped amounts) that the raw oil-shale ore in the skirt portion **21** is maintained, preferably, between low level **189** and high level **191**. Preferably, the level should be at **193**, about midway between levels **189**, **191**. The rotary feeders **45** also operate at such a rate that the frusto-conical chute members **43** are maintained substantially empty.

If, at any time, the level of raw oil-shale ore falls below low level **189**, to a level such as at **195**, then an emergency control unit **197** sounds an alarm and either slows the rate of operation of the grate discharge mechanism **119**, or stops the discharge mechanism for a period of time that is long enough to allow the level of raw oil-shale ore to rise to level **193**. Thereafter, the discharge mechanism resumes normal operation under control of the regulator **187**.

If, on the other hand, a hang-up occurs in the retort, that interrupts the normal uniform downward movement of the oil-shale ore so that the raw oil-shale ore rises to a level **199**, then another emergency control unit **201** sounds an alarm and either slows the raw shale-oil feeding conveyor belt **41** (FIG. 1), or stops it for a period of time that is sufficient to dislodge the hang-up.

In such instances, the control unit **201** also regulates the bells **25, 27** so that no additional raw oil-shale ore may be discharged from the upper **33** and lower **35** chambers into the skirt **21**. After the level of raw oil-shale ore returns to level **193**, raw oil-shale ore feeding conveyor **41** and bells **25, 27** resume normal operation.

The bells **25, 27** are operated sequentially by the controller (not shown) that controls the rate of speed of the belt conveyor **41**. Neither the upper **33** nor the lower **35** chambers is ever completely full, and it is preferred that the volume of the upper chamber **33** be not greater than the allowable working volume of the lower chamber **35**.

In some applications, it is possible to obtain better control of the temperature throughout the mid-portion of the retort furnace, and thereby obtain more effective liberation of kerogen and the volatile shale-oil gases from the ore. This can be accomplished, without heating the oil-shale ore particles to temperatures within the range (2000° to 2200° F.) in which fusion of the oil-shale ore particles takes place, by burning recycle gas in an auxiliary combustion chamber of conventional design located outside of the retort furnace. The products of combustion produced in such an auxiliary combustion chamber will be at a temperature below the fusion temperature range and when such products of combustion contact the raw oil-shale ore, clusters will not form.

When hot products of combustion are produced in such an external combustion chamber and conveyed to the internal distributors, such as distributor **79, 89**, suitable temperature measuring means, such as the thermocouple **109** in device **103**, may be used, and a signal from such temperature measuring device actuates a gas-air controller to feed the products of combustion at a proper temperature and at a proper rate so that the temperautre as measured by device **109** is within the desired limits.

The remainder of the recycle gas not used in the auxiliary combustion chamber would be added to the lowermost distributor **101, 81** near the bottom of the retort at a rate sufficient to maintain the temperature of the spent oil-shale ore discharging from the retort in the range of between 100° and 400° F.

In a preferred embodiment of the invention, the lower bell **27** should be so located, with respect to the desired level **193** of shale ore in the skirt portion **21**, that, when the lower bell **27** is opened, the shale ore falls in a path that meets the level **193** at a locus about midway between the skirt wall **21** and the vertical central axis of the skirt portion **21**.

Although the invention has been described herein with a certain degree of particularity, it is understood that the disclosure has been made as an example and that the scope of the invention is defined by what is hereinafter claimed.

What is claimed is:

1. Apparatus for retorting oil shale ore containing kerogen comprising:

(a) a vertical shaft furnace having an inlet at the top and one or more outlets at the bottom;
(b) gas sealing means at the top of said shaft furnace including an arrangement of movable members axially disposed one above the other to prevent leakage of gases from said furnace and providing an inlet for raw shale ore into said furnace;
(c) grate means adjacent the bottom of said furnace for supporting the weight of oil shale ore in said furnace and for the discharge of spent shale ore at a controllable rate;
(d) first distributor means above said grate for introducing fuel gas into said retort furnace, which gas cools the shale ore adjacent said distributor;
(e) second distributor means located in vertical spaced apart relation to and above said first distributor means for introducing ambient air into said shaft furnace, said air mixing with the fuel gas rising from said first distributor and burning in a combustion zone of said furnace adjacent said second distributor thereby heating said shale ore;
(f) third distributor means located in vertical spaced apart relation to and above said second distributor means and below said top gas sealing means;
(g) horizontal tubular means supporting said first distributor;
(h) horizontal tubular means supporting said second distributor;
(i) horizontal tubular means supporting said third distributor;
(j) a vertical columnar tubular member communicating with and supporting each said horizontal support means;
(k) means to introduce into said vertical columnar member cooling gas which flows into each horizontal support member and cools the same;
(l) means to draw into said third distributor and to conduct away from said furnace the gases produced by burning said gas and air mixture and the volatile derivatives of said kerogen which are liberated from the shale ore when subjected to the heat of said burning gas-air mixture;
(m) valve means for controlling the flow of gases into said first distributor;
(n) valve means for controlling the flow of air into said second distributor;
(o) means for cooling and condensing the liquid derivatives of said kerogen and separating the gaseous derivatives from said liquid derivatives;
(p) means for removing said condensed liquid derivatives;
(q) means for removing and cleaning said gaseous derivatives;
(r) means for directing a portion of the gaseous derivatives through a flow control apparatus and into said first distributor;
(s) a temperature profile controller apparatus;
(t) means connecting said temperature profile controller apparatus to said flow controller, said cooling and condensing means, each of said temperature sensing elements,

said valve means for controlling the flow of gases to said first distributor, said valve means for controlling the flow of air to said second distributor, and said means for drawing the derivatives of kerogen and other gaseous products into said third distributor and away from said furnace, whereby the temperature at respective levels in said furnace is maintained within a preselected range of values for each respective level.

2. The structure of claim 1 including:

(a) means for actuating said grate to discharge spent shale ore at a controlled rate whereby the level of

raw shale ore in said furnace moves downwardly uniformly and steadily; and
(b) means for discharging the spent shale ore from below said grate.

3. The structure of claim 2 wherein:
(a) said spent shale ore discharging means includes at least one rotary feeder.

4. The structure of claim 2 wherein:
(a) said spent shale ore discharging means includes a flapper valve and mechanism for actuating said flapper valve.

5. The structure of claim 4 including:
(a) a first compartment disposed beneath the bottom of said furnace with which said first flapper valve cooperates to close said compartment and retain spent shale ore therein;
(b) a second compartment located beneath said first compartment and a second flapper valve cooperating with said second compartment to close the bottom thereof;
(c) mechanism for actuating said second flapper valve; and
(d) means for removing particulate matter from around the discharge of said flapper valves when they are open and when spent shale ore discharges through said valve.

6. The structure of claim 3 including:
(a) a tubular member annularly surrounding said rotary feeder; and
(b) means for removing particulate matter from said tubular conduit when said rotary feeder is operating.

7. The structure of claim 6 including:
(a) means for conducting discharged spent shale ore from adjacent the furnace discharge means.

8. The structure of claim 7 including:
(a) means for cleaning the dust laden air removed from the tubular conduit surrounding said rotary feeder.

9. In a vertical retorting furnace having therein a plurality of horizontal distributors for a fuel mixture that is burned in said furnace, each distributor having fluid conductive cooling passages, the improvement comprising:
(a) a vertical tubular member within said furnace supporting said distributors;
(b) means to flow cooling fluid through said vertical member;
(c) means to flow cooling fluid in said distributors to cool the same; and
(d) means to remove said cooling fluid from said distributors.

10. The invention of claim 9 including:
(a) a tubular member fluidly communicating with said vertical member and extending generally radially outward therefrom within said furnace;
(b) means maintaining said tubular member in such position;
(c) means closing the outer end of said tubular member;
(d) a thermocouple element resident in said tubular member; and
(e) lead wires connecting said thermocouple element to a temperature indicating device whereby the temperature within said furnace at the level therein where said temperature sensing device is located is indicated.

11. Apparatus for obtaining product oil and gas by the destructive distillation of oil shale comprising:
(a) a vertically elongated retort furnace;
(b) oil shale feed means for introducing oil shale into the upper end of said furnace;
(c) product removal means for removing product oil and gas from the upper end of said furnace;
(d) heating means for introducing fuel and oxygen into said furnace to supply the heat for said destructive distillation;
(e) a central axial hollow column in said furnace supporting said product removal and heating means; and
(f) a grate at the bottom of said furnace for controlling the discharge of oil shale from the furnace.

12. The apparatus of claim 11 wherein:
(a) said heating means comprises a fuel distributor and an air distributor, with
(b) each heating means comprising a plurality of tubes of generally circular cross section extending horizontally across the furnace, the tubes having openings at the sides for the flow of gas and fuel therethrough; and including
(c) a header for each distributor surrounding said furnace and communicating with said tubes; and
(d) individual covers for the top of each tube, said covers forming a conduit for the flow of coolant to protect said tubes.

13. The apparatus of claim 12 wherein:
(a) the fuel distributor is at a low elevation and the air distributor is at a high elevation whereby the fuel becomes heated in passing upward in the furnace from the fuel distributor and becomes ignited upon reaching the air distributor to supply heat for the destructive distillation of said oil shale.

14. The apparatus of claim 11 including:
(a) a plurality of temperature sensors projecting outwardly from said column at selected vertical intervals for providing a temperature profile for the internal mass in the furnace.

15. The apparatus of claim 14 including:
(a) means responsive to said temperature sensors for controlling said heating means.

16. The apparatus of claim 11 wherein:
(a) the product removal means comprises a plurality of off-takes extending across said furnace, each of said off-takes being of substantial height and width and having an upwardly extending top and an open bottom, the ratio of said height to width being between 5:1 and 1:2.

17. The apparatus of claim 10 including:
(a) an aperture in said vertical member at a location opposite said tubular member providing access for servicing and maintaining said thermocouple element in said tubular member; and
(b) a removable cap disposed over said aperture.

18. The apparatus of claim 11 including:
(a) arms extending from said column and communicating with the interior of said hollow column, said arms supporting said product removal means and said heating means;
(b) means for flowing a cooling fluid in the interior of said hollow column and in said arms; and wherein
(c) said oil shale feed means comprises a plurality of superimposed chambers with internal bells separating one chamber from its next adjacent lower chamber and separating the lowermost chamber from the furnace interior; and including
(d) a skirt connecting said oil shale feed means to said furnace;
(e) a plurality of rings disposed in said furnace coaxially of the said skirt with
   (i) each of said rings being displaced vertically from the other with the diameter of each lower ring being greater than the ring immediately above it; and with
   (ii) said rings having their loci within a conical surface whose angularity with the horizontal plane is greater than the angle of repose of the oil shale particles, whereby the larger pieces of oil shale are constrained against movement outwardly to separate from the smaller particles, and the tendency of the smaller particles to move toward the axis is interrupted by said column, and whereby the oil shale charge in

said furnace tends to move in laminar flow downwardly in said furnace;

(f) a level sensor for sensing the level of oil shale in said skirt;

(g) means responsive to said level sensor which actuates said grate to maintain a predetermined level of said oil shale in said skirt; and

(h) means for moving said bells to open said chambers in series.

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