United States Patent

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[54] **METHOD OF AND APPARATUS FOR CARRYING OUT A CHEMICAL OR PHYSICAL PROCESS**
15 Claims, 9 Drawing Figs.

[52] U.S. Cl. 23/1, 166/59, 23/283, 23/285, 210/63
[51] Int. Cl. C01g 1/00
[50] Field of Search .... 203/100; 210/63; 166/57–59, 11, 39; 159/16 A; 23/285, 283, 1

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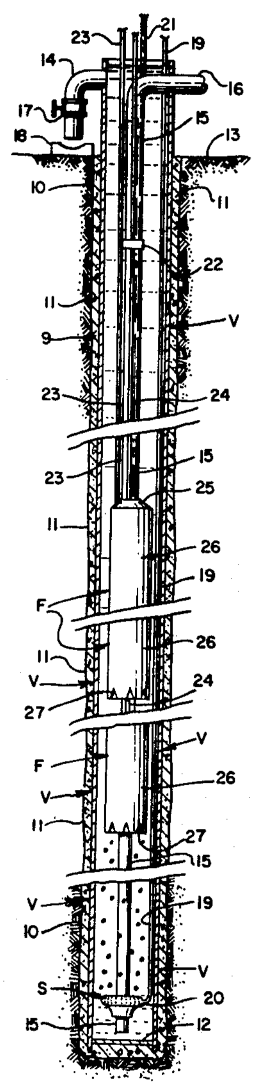
ABSTRACT: This invention is essentially an improved means for contacting solids, liquids, and gases at elevated pressures and at desired temperatures, for providing inherently stable pressures, for conserving the heat of chemical reactions, and for minimizing the power requirements for pumping liquids continuously through a high-pressure zone. The invention is particularly useful for processes utilizing physical, chemical, and/or thermal treatment, under elevated pressures, of continuously flowing streams of large volume which may contain suspended solids.



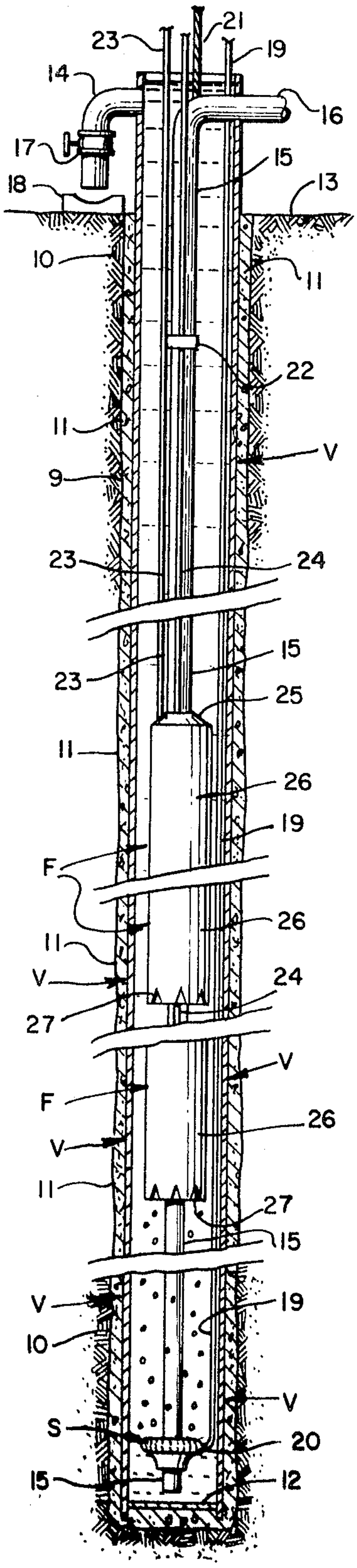


FIG. 1

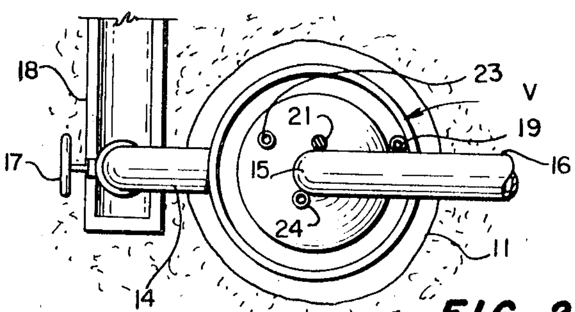


FIG. 2

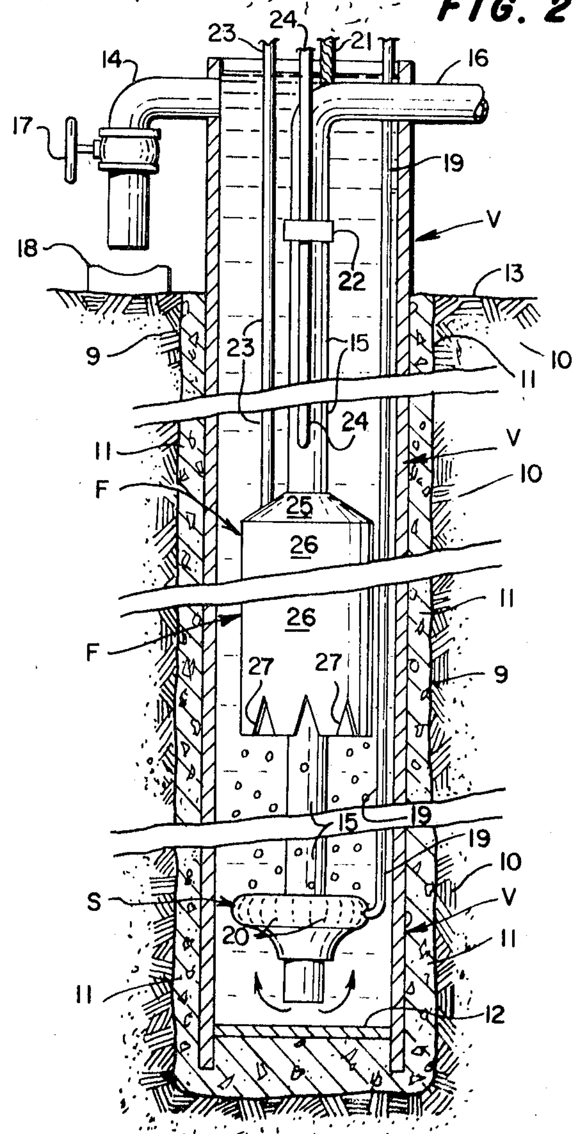


FIG. 3

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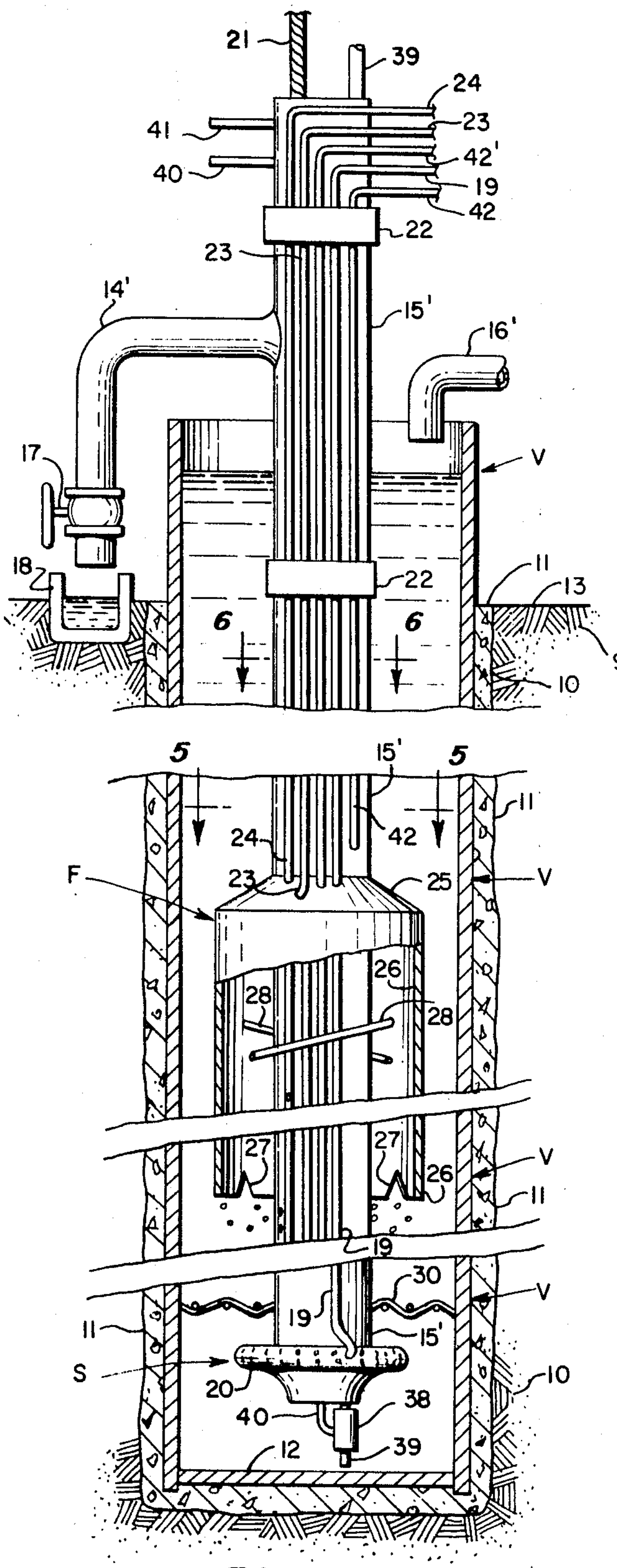

FIG. 4

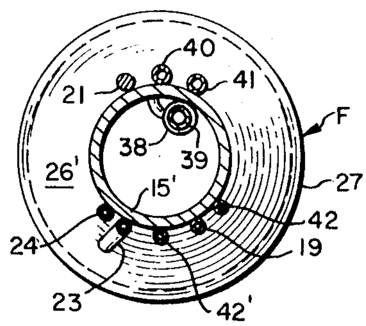

FIG. 5

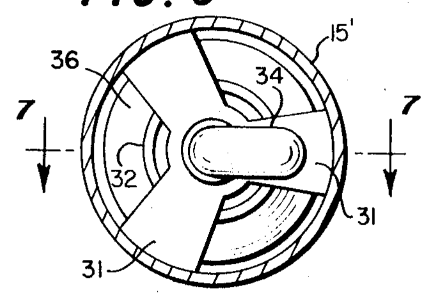

FIG. 6

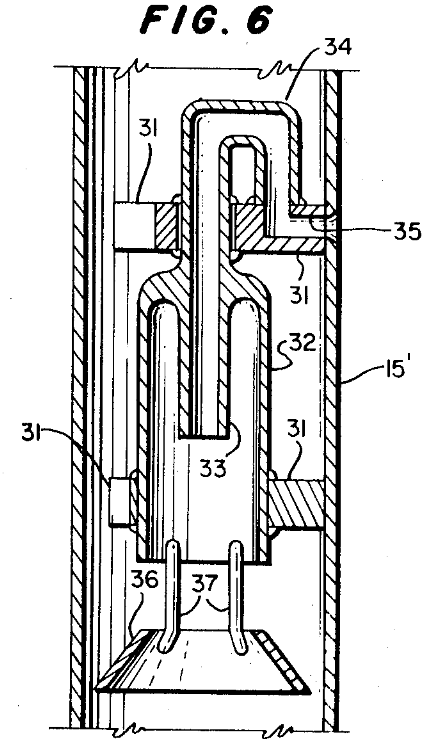

FIG. 7

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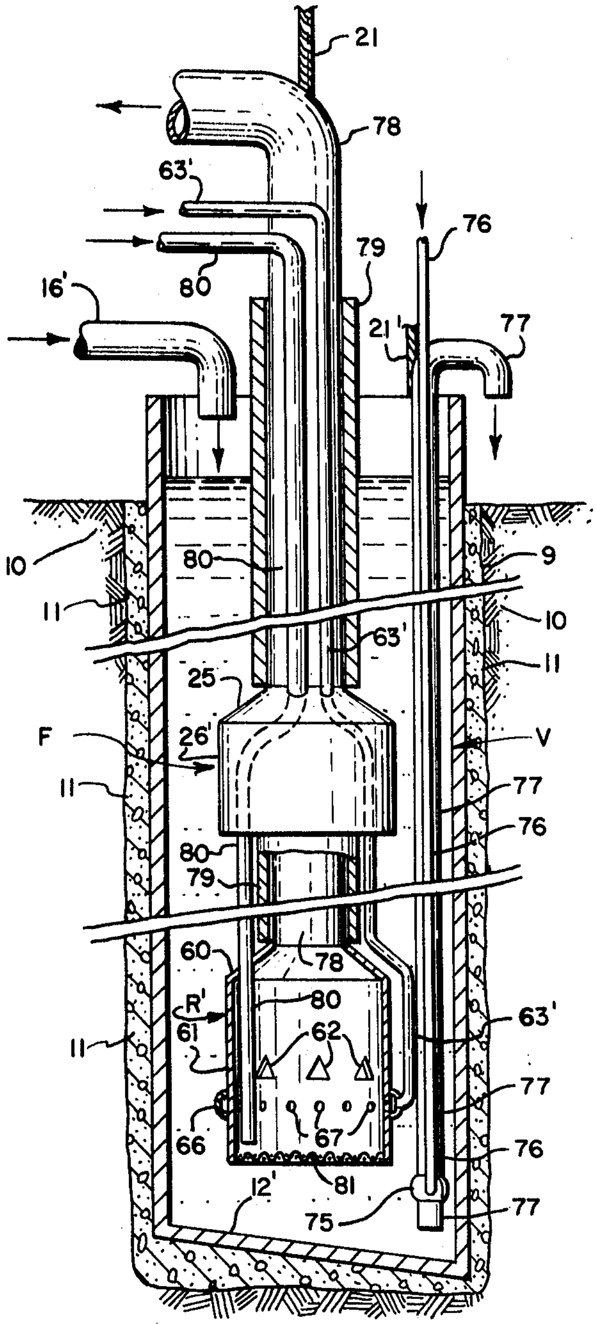

FIG. 8

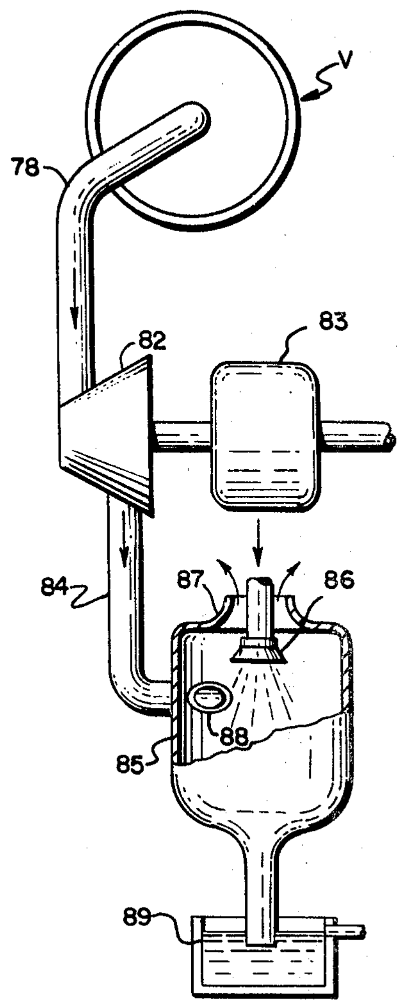

FIG. 9

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METHOD OF AND APPARATUS FOR CARRYING OUT A CHEMICAL OR PHYSICAL PROCESS

The invention is based on the realization that deep boreholes, suitably lined, can be utilized as a particularly efficient apparatus for physical, chemical, and/or thermal processes. The hydrostatic pressures created when the boreholes are filled with liquids or fluidized solids are of sufficient magnitude to promote a great many useful chemical reactions, and there are many other advantages, as partially noted later, that appear in a unique combination when deep boreholes are regarded as an item of process apparatus, rather than as a means of access to water, petroleum, or mineral ores.

The following processes are illustrative of the many possible embodiments of this invention:

1. The oxidation of continuously flowing waste streams, such as sewage, cannery wastes, pulpmill wastes, or packinghouse wastes. More generally, any water solution or suspension of combustible solids, such as ground paper, powdered coal, oil shale, or other such material can be oxidized or or contacted with other suitable chemicals, such as hydrogen or chlorine, under high pressures and suitable temperatures. Further, such gaseous chemicals may either be pumped into the apparatus or formed in situ, for example, by electrolysis. Solid and liquid reactants can enter the apparatus under gravity or via low-pressure pumps. Useful reaction products may be recovered and/or the chemical energy may be utilized as described below.
2. A particularly useful chemical reaction involves oxidation of dissolved or suspended, combustible materials in liquid water at elevated temperatures and pressures. Thus, powdered coal or other combustible material may be used to produce steam at high pressures for power generation or for continuous distillation of fresh water. Either process will produce fresh water from salt or brackish water or from waste streams. Other uses of steam, such as for secondary petroleum recovery operations, should also be noted.
3. The reaction zone pressures may be established either by liquids or by particulate solids. The solids may be fluidized by gases or liquids or they may be unfluidized and establish the reaction zone pressures by restricting the outflow of gases from the reaction zone. Thus, solids that may or may not be catalytically active can be preheated in order to treat gases thermally at elevated pressures, as in the cracking processes used in refineries. Alternatively, powdered coal may be contacted with steam and/or oxygen or with hydrogen in this apparatus, under elevated pressures, to produce desirable products.

In the apparatus, the conduit extends downwardly to the reaction zone and a hollow bell or similar device is connected to the conduit and receives a gas, as by collecting gaseous resultants of reaction therein, to provide buoyancy to assist in supporting the conduit.

This invention relates to chemical reactions and processes, and also to apparatus particularly adapted to carry out such reactions and processes, including but not limited to those involving either the continuous flow or batchwise contacting of gases, liquids and solids, in any combination. Specific example of such processes comprise the production of sulfuric acid and other chemicals, the generation of steam, the treatment of waste streams, the desalination of sea water or other brackish waters, and other reactions and processes. This invention relates specifically to reactions and processes which are to be carried out at elevated pressures, which range upward to many thousands of pounds per square inch, and to the vessel and associated apparatus for carrying out such reactions and processes.

Previous types of apparatus utilized for this purpose have all comprised the combination of a pump, which generates all the pressure, with a pressurized vessel. Reactants are pumped into the vessel, rmeain at elevated pressure during their retention in or passage through the vessel, and exit through a control valve or orifice. This conventional practice has a number of disadvantages, including:

1. The pumps require substantial amounts of power. The amount of power, in a given case, can be closely approximated from the product of the pressure increase at the remain and the volume rate of liquid passing through the pump. In the absence of expensive power recovery devices, such as liquid-driven turbines, all this power input is wasted. As a result, large amounts of liquid cannot be economically passed through the conventional pressure vessel, particularly where high pressure is involved.
2. The internal dimensions and the operating characteristics of the pump and the outlet valve or orifices impose stringent limitations on the size and hardness of solid particles passing through the pressure vessel. An escape from these limitations would save the grinding costs connected with the passage of solid particles through conventional pressure vessels and would allow hard solids, such as ores, oil sands and oil shales, to be processed continuously at high pressures.
3. Sealing and packing problems are common at glands where wires, rods or shafts extend through the vessel walls for such purposes as agitation or measurement of the contents. High costs related to leakage and maintenance of these devices are common.
4. Pressure control apparatus is complex, expensive and easily damaged by solid particles passing through a conventional pressure vessel and also by corrosive materials. Improvements, wherein pressure control may be inherent in the vessel design and where it functions independently of solid particles and corrosive chemicals, would greatly extend the usefulness of high-pressure technology. Such a vessel would also be safer from bursting pressures that develop from malfunctioning of pressure control apparatus.

Among the objects of this invention are to provide novel chemical reactions and processes involving particularly those which are to be carried out at relatively high pressures and elevated temperatures; to provide such reactions and processes which are carried out in a manner such that the size and hardness of solid material supplied to and/or removed from the reaction zone may be greatly in excess of that to which solid material supplied to a conventional pressure vessel is limited; to provide reaction zones of great depths which greatly extend contact between solid, liquid and gaseous reactants; to provide such reactions and processes which may be carried out with a minimum pumping power input that is much below that necessary in current practice; to provide such reactions and processes in which the problem of sealing entrances and exits to the reaction zone are minimized; to provide such apparatus which is adaptable to many different types of reactions and processes, including but not limited to waste stream treatment, desalination, combustion, hydrogenation, oxidation, polymerization, chlorination, sulfuric acid production, steam generation, treatment of oil shales and sands, ores, and others; to provide apparatus in which the reactions and processes of this invention are particularly adapted to be carried out; to provide such apparatus in which countercurrent heat exchange between incoming and outgoing material and among solid, liquid and gaseous reactants is readily effected; to provide such apparatus which may utilize preexisting structures; to provide such apparatus with inherently stable reaction zone pressures, which remain unaffected by entry and exit of fluids and solids and corrosive materials; to provide such apparatus which may be readily varied in size and capacity, and which is suited for continuous or batch operation without increase in the problems of feed or withdrawal of material; and to provide such reactions and processes, as well as such apparatus, which will operate effectively and efficiently for the desired purposes.

This invention is based on the realization that the above objectives, in combination, can be obtained through the utilization of the hydrostatic pressure obtainable at depths sufficient to produce pressures obtainable in conventional apparatus only by mechanical pumping equipment. These depths are such that deep boreholes, many thousands of feed deep, which were formerly utilized only for access to water, petroleum or other minerals, have now found a new type of apparatus use.

The chemical reactions and the processes of this invention are thus carried out at elevated pressures by utilizing a hydrostatic head to furnish the desired pressure, thereby involving a vertically elongated reaction vessel. In principle, the reaction vessel is the hydraulic equivalent of a U-tube. Liquid feed enters the top of the vessel, progresses downward through increasing hydrostatic pressures, passed through the reaction zone, and the reaction products then exit upward through decreasing pressures to the surface. Solid and gaseous materials may also be passed into the reaction zone by modified procedures detailed later.

Such a reaction vessel is conveniently mounted in a vertical passage extending to a position within the earth at which the hydrostatic head will be sufficient to produce the desired reaction pressure, such as in excess of 1.000 pounds. For instance, at a depth of 4,310 feet, the hydrostatic head of a liquid having a density corresponding to water is approximately 1,870 pounds per square inch. As will be evident, the depth at which the chemical reaction is to take place may be readily selected, so that the reaction pressure will be equal to or greater than the necessary minimum. The reaction vessel itself may be similar to the casing of an oil or gas well, so that abandoned or dry oil or gas wells are readily usable for such purpose. If desired, such wells may be enlarged by supplemental drilling, if the diameter at depth desired is insufficient to accommodate the diameter of the reaction vessel; alternatively, large underground chambers may be mined and, if desirable, fitted with separate entrance and exit passages. In addition, construction on the surface may be appropriate where sufficient natural elevation is present; a mountainside, for example.

As will be evident, the pressure within such a vertically elongated reaction vessel is proportional to the depth and, at the surface, may be atmospheric or slightly above atmospheric. Thus, the liquid movement may be via gravity flow, without pumps, or via low-pressure pumps, and a minimum pumping power is thus required because the pressure increase at the pumps is low; the product of the pressure increase and the volume rate will be small, even though the volume rate may be large and the reaction zone pressures are high.

The low input pressure permits use of relatively large-diameter pipes, so that relatively large pieces of solid material, i.e. compared to the size which will readily pass through the valves and piping of a high-pressure pump, may be introduced directly into the reaction zone; large pieces of solid materials also may be introduced directly into the top of such vertically elongated reaction vessel. Examples of such solid material include solids in waste streams, coal, wood, oil shale, ores and other solids.

Leakage and binding problems associated with seals and glands are avoided because the wires, rods or shafts used for agitation or measurements within the reaction zone have no effect on the hydrostatic pressure gradient that maintains pressure in the reaction zone; the gradient functions along the surfaces of these devices, just as it does in their absence. The pressure gradient also remains substantially unaffected by moderate volumes of gas, such as compressed air, that may be utilized for agitation or other purposes.

The hydrostatic pressure gradient also remains substantially undisturbed by fluid flow into and out of the reaction zone, by solids passing through the vessel, or by corrosive materials. Gas bubbles affect the gradient moderately, but their effect is proportional to the displacement of these bubbles, and can be allowed for in the vessel design. Thus, pressure control is an inherent feature of this kind of vessel, and it is superior to existing pressure control mechanisms, for the reasons given.

Appropriate reactions can also be carried out in a fluid having a density greater than water, thereby reducing the total height of the pressure vessel. Furthermore, additional pressure can be added at the surface, i.e. at the top of the pressure vessel, to increase the hydrostatic head below, when such additional pressure does not interfere with the introduction of the feed.

Fluidized solids have many of the same hydraulic characteristics as liquids and, for that reason, are also suitable for use in this invention to provide reaction zone pressures and/or as reactants.

The reaction vessel of this invention is also inherently safer than high-pressure vessels at the surface, since conventional mechanical pressure controls are not necessary. Any rupture at the bottom will be confined by the surrounding earth, while operators and the controls are remote from the high-pressure zone at the bottom. Thus, sewage treatment, power generation, or other reactions at high pressures can be conducted safely in or near population centers.

A number of advantages, in addition to those listed above, ensue when using a vertically elongated pressure vessel, particularly one extending into the earth, among them being the following.

Heat losses are greatly reduced because of the surrounding earth; thus, processes which require careful heat conservation, such as waste stream treatment, become feasible in this apparatus. In the event that loss of heat to the surrounding earth becomes a problem, the elongated pressure vessel may be insulated at the reaction zone, or a double-walled vessel may be used at the reaction zone. In addition, hot gaseous or liquid products of the reaction may be removed through a pipe extending upwardly from the reaction zone and centrally of the reaction vessel, so as to be surrounded by the downwardly moving feed to the reaction zone, thereby providing efficient and effective countercurrent heat exchange, to preheat the feed. The balanced pressures existing throughout the vessel permit such pipes to be thin and thus enhance their heat exchange capacity and reduce their cost.

Where gases are generated internally in the reaction zone, they may be collected by a bell, similar to a diving bell, situated at the upper limit of the pressurized zone. These gases are available for continuous delivery at the upper end of the reaction vessel and at the pressure existing at their point of collection. Thus, they may b used to develop power just as if they were produced in a conventional pressure vessel.

Solids of comparatively large dimensions, present in waste streams, may be fed into the pressure vessel from the top and reacted directly in the reaction zone below. Coal may be fed directly to the reaction alone to furnish high-pressure steam or gases, following combustion, for operating a turbine or the like to produce power. Oil shale, oil sands or coal may be fed downwardly to the reaction zone to be chlorinated, oxidized or hydrogenated and to furnish materials, for example, which may be recovered. Salt water may be supplied to flow by gravity to the reaction zone, where it is evaporated by combustion of coal or other fuel fed in a similar manner to the reaction zone, thereby producing fresh water condensate. Heat exchange surfaces at which steam forms may comprise the surfaces of the fuel particles themselves and the combustion gas; thus, scale, remaining from evaporated brine, cannot reduce heat exchange efficiency, as it does when heat passes through a metal surface.

As an additional feature, any accumulation of sludge or fuel ash, or other insoluble material, below the reaction zone, may be removed continuously or intermittently, if desired, by an air or gas lift pump, or by any other kind of suitable pump located on the surface; siphons are equally suitable, provided the pressure vessel is extended to a sufficient height, say, 10 feet or more, above the siphon outlet.

Other features of this invention, as well as the manner in which the above objects and requirements are met, will be apparent from the description which follows, taken in connection with the accompanying drawings, in which:

FIG. 1 is a condensed, vertical section of apparatus including a vertically elongated pressure vessel, constructed in accordance with this invention and installed in a well or similar passage extending down into the earth for the depth necessary to produce, through hydrostatic head, the pressure necessary for carrying out desired chemical operations, such as reactions requiring solid, liquid and gas contact, in any combination, at high pressure;

FIG. 2 is a top plan view, on an enlarged scale, of the apparatus of FIG. 1;

FIG. 3 is a further condensed vertical section, on a further enlarged scale, illustrating with greater clarity certain of the components of the apparatus of FIG. 1;

FIG. 4 is a condensed, vertical section, similar to but on a slightly larger scale than FIG. 3, of apparatus for contacting solids, liquids and gases, in accordance with this invention, alternative to that of FIG. 1;

FIG. 5 is a central horizontal section, on an enlarged scale, taken along line 5—5 of FIG. 4;

FIG. 6 is a central horizontal section, on an enlarged scale, taken along line 6—6 of FIG. 4;

FIG. 7 is a fragmentary, vertical section, taken along line 7—7 of FIG. 6;

FIG. 8 is a condensed vertical section, similar to FIG. 4 but showing an embodiment of the apparatus of this invention which is particularly adapted to be utilized for the generation of steam through high-pressure oxidation of coal or other fuel, for power generation purposes, and which, in a substantially identical configuration, would also serve for collection of reaction gases, other than steam, and their subsequent delivery at high pressure, such as volatiles from the hydrogenation or gasification of coal or oil shales;

FIG. 9 is schematic diagram of the power components which may be utilized in connection with the apparatus of FIG. 12, including a steam-gas-driven turbine and a spray condenser therefor.

Apparatus constructed in accordance with this invention, particularly suited to contacting solids, liquids and gases, under pressure, is illustrated in FIGS. 1—3. The contacting of continuously flowing waste streams, such as municipal sewage, with air or oxygenated air, elevated pressures, is one application. As in FIG. 1, the apparatus includes a vertically elongated, upright reaction vessel V which is conveniently formed of connected tubular sections, similar to a well casing, with the tubular sections at lower levels being thicker, to withstand greater pressure, if desired. Reaction vessel V is installed within a well 9, drilled downwardly into the earth 10, with concrete 11 set around the reaction vessel within the well for support and reinforcement of the reaction vessel. The well 9 may be a dry well originally drilled in an attempt to penetrate an oil or gas deposit, used as drilled if of sufficient diameter, or enlarged in diameter to the extent necessary. As will be evident, if the well has been drilled through a hard, impervious strata, the casing shown as forming the reaction vessel V may be eliminated over such zones. However, such zones should be carefully selected, so that leakage through fractures, vugs or the like does not interfere with the desired operations. The lower end of the vessel V may be closed by a plug 12, while the upper end may extend above the ground surface 13 to a suitable height; generally such height is that necessary for a liquid height sufficient to provide sufficient flow through an outlet 14 or to provide sufficient head for efficient operation of siphons, described later, which operate as scavenging pumps in some versions of this invention.

It will be noted that a well-known oxidation reaction referred to as "flameless combustion" will proceed at temperatures near 600° F., so long as liquid water is present. Since pressures near 1,574 pounds per square inch are necessary to maintain liquid water at 600° F., the depth corresponding to this pressure, for a water-filled vessel, is near 3,640 feet. Thus, depths in vessel V exceeding 3,640 feet will provide the reaction pressures necessary for oxidation at temperatures near 600° F., of combustible materials in waste streams, such as municipal sewage. Reactions, such as flameless combustion, have finite completion times, and it is necessary that vessel V have a sufficient volume below a given minimum depth, such as 3,640 feet derived above, to permit completion of a given reaction; the required volume will depend on the reaction velocity and the reactant flow velocity through vessel V.

As further shown in FIGS. 1-3, a feed pipe 15 extends vertically and centrally of vessel V, to which the liquid to be treated, such as sewage, is supplied continuously through an inlet pipe 16 and from the lower end of which the liquid is discharged, near the bottom of may be used, as shown. The floats, whose bouyancy V, as indicated by the arrows of FIG. 3. The liquid then moves upwardly along the outside of pipe 15, past a sparger S and a series of float bells F to the outlet 14 having a control valve 17, to drain away through a trough 18. Air or oxygen, in this example, is pumped through a pipe 19, through the sparger S, which is conveniently an alundum ring, transversely arcuate and provided with a series of discharge holes or slots 20 therein, and mixes intimately with the liquid feed discharged from the bottom of pipe 15. Oxidation occurs as the liquid and gas rise concurrently and combustible materials in suspension or in solution will be thus largely destroyed.

The heat from reactions, such as flameless combustion, is transferred from the reaction products through the walls of pipe 15 to the incoming feed, while the reaction products flow upward for several thousand feet toward outlet 14; thus, the outlet stream of this apparatus need be only slightly warmer than the inlet, even though the reaction zone may be several hundred degrees. Heat conservation is thus an inherent feature of the invention and greatly extends its usefulness to such streams as municipal sewage which have small organic content and, accordingly, generate relatively little heat during combustion. A further inherent advantage of the invention is that pipe 15 may have very thin walls, because pressures are balanced throughout the apparatus, and such walls improve heat transfer characteristics.

Pipe 15 is, of course, vertically elongated to have the same height as vessel V and thus should be supported, as by a cable 21, attached to pipe 15 by clamps 22 at spaced vertical positions. Normally, additional support for pipe 15 is desirable and this is provided by floats F, which provide extra support through their buoyancy, while multiple floats may be used, as shown. The floats, whose buoyancy is proportional to their height, for a given diameter, have a substantially constant displacement, as long as gas escapes from slots 27 of float F. Product gases and unreacted feed gases from the reaction zone rise to fill the floats; such gases then may be withdrawn through a pipe 23 or 24, preferably one such pipe for each float, at the pressures existing at the bottom of the float, as for power production or to operate gas lift pumps at higher levels inside vessel V. Each float F may also be initially filled by air or gas pumped down through pipe 23 or 24. Gas bubbles trapped by the floats are blocked from the upper parts of the vessel V, thus increasing the effective density of fluids in these regions and increasing or maintaining the desired hydrostatic pressure gradient.

It is preferable that floats be well above the reaction zone, so that only product gases will be trapped; where structural requirements place floats in the reaction zone, additional spargers S may be installed, one above each such float, and the reactant gas feed should be proportioned among these spargers.

Each float bell F, as shown, may comprise a conical upper head 25 which angles downwardly from the central feed pipe 15 to an elongated cylindrical skirt 26, the lower edge of which is provided with a series of slots 27 to minimize bubble size when gas escapes and to circumferentially distribute the flow of such gases escaping from the bottom of float F. Each float F may be reinforced on the inside, in the same manner as shown in FIG. 4, by a series of angularly extending rods 28 attached, as by welding, to the inside of skirt 26 and to the central pipe, at points of tangency to the latter. Clamps 22, which attach cable 21 to pipe 15, may also be utilized to attach air line 19, gasline 23 and such other conventional apparatus, not here shown, as thermocouple wires, pressure indicators and the like.

In order to remove sediment that may accumulate in the bottom of vessel V, a scavenger pump, such as described in connection with FIG. 4, may be installed. This may be a conventional gas lift pump, operated by gas from a compressor, or, conveniently, with gas from pipe 23 or 24; this latter alternative requires that the gas entrance to the pump be located above the float bell which supplies the gas; alternatively, if the upper liquid surface in pipe 15 has sufficient elevation above the ground surface 13, a siphon will operate satisfactorily as a scavenger pump. If desired, power-driven pumps of any kind, located on the surface, will also operate satisfactorily as scavenging pumps, provided their inlet pipes extend deeply enough into vessel V.

An alternative form of apparatus, illustrated in FIGS. 4–7, may be utilized in lieu of that shown in FIGS. 1—3. In FIG. 4, the reaction vessel V, earth 10, well bore 9, concrete 11, plug 12, surface 13, trough 18, cable 21, clamps 22, pipes 23 and 24, float bells F and sparger S are the same as previously shown and described.

The apparatus of FIGS. 4–7 differs from the apparatus of FIGS. 1–3 primarily in the flow of liquid reaction products upwardly inside a central pipe 15′, thence through a discharge pipe 14′ and valve 17, and the feed into the upper end of vessel V of liquid feed or liquid-solid dispersion feed by a feedpipe 16′, to pass downwardly past gas bubbles from sparger S or from the reaction zone. As will be evident, with the sewage flowing downwardly and the air or oxygen containing gas bubbling upwardly, the reactants will be flowing in a counterflow relation, thereby contributing toward the more effective oxidation and removal of combustible materials which comprise the objectionable part of most waste streams. Solids need not be fed to the reaction zone as liquid-solid dispersions; they may be fed, for example, from a hopper or continuous belt, directly into the top of the apparatus, as at the same position as feedpipe 16′. Such solids will fall directly through the liquid and downwardly into the high-pressure zone, without the necessity of any pumping, provided they are small enough in size to pass through the annular space between skirt 26 of the float bells and pressure vessel V. Thus, the dimensions of such solids may be very large, in comparison with those suitable for feed to conventional pressure vessels. A rod or wire mesh or grid 30 is mounted on pipe 15′ above sparger S, to insure that larger solid particles will remain within the reaction zone until completely reacted.

As stated previously, conservation of the heat of reactions is an object of this invention, and the counterflow heat exchange which occurs between the feed and the product streams, through the walls of pipe 15′, serves this object. However, if flow rates are continuously increased, the heat exchange rate through pipe 15′ will eventually become inadequate, for a given construction, and hot liquid from the reaction zone will rise, inside pipe 15′, without being sufficiently cooled, to regions where the hydrostatic pressure is low enough for the liquid to boil or flash into vapor. For example, at 3,000 feet depth, water will reach a temperature of about 580° F. without boiling, but if this water is rapidly raised, without cooling, to 2,000 feet, it will flash into vapor and form enough steam to cool the remaining water to about 530° F. The vapor thus formed would bubble toward the top of pipe 15′ and the heat of vaporization contained therein would be partly degraded to lower temperatures by condensation at lower pressures and partly lost from the apparatus. Noncondensible gases also tend to be carried into pipe 15′ from the reaction zone, and they will mix with the vapor and bubble to the top of pipe 15′, carrying substantial amounts of heat with them. In addition to the direct heat losses involved, vapors and gases will reduce heat transfer rates through metal surfaces, such as the walls of pipe 15′, when they are mixed with liquids. Thus, in order to maximize the flow rate for a given construction, some means to recover heat from vapors and gases becomes desirable.

One way of recovering the heat contained in vapors and gases is to contact them directly with the incoming feed stream at the top of the vessel V, using a device such as a spray tower. However, where large amounts of vapor are involved, the feed stream will be appreciably warmed and its heat absorption from the walls of pipe 15′ correspondingly reduced; in this situation, heat conservation will be improved if the vapor is conducted directly into the feed stream near its level of formation and hear its formation temperature. The incoming feed stream, above the vapor entrance point, will thus remain cooler and will therefore absorb heat more efficiently from pipe 15′. Noncondensible gases from the reaction zone, inside pipe 15′, should also be directed into contact with the incoming feed at a point as near he reaction zone as possible.

A preferred one of several vapor-gas separation devices suitable to contact vapors and gases with the incoming feed, in the manner just described, is shown in FIG. 6, corresponding to a position inside and adjacent the upper end of pipe 15′; the remainder of the devices may be installed at graduated intervals inside pipe 15′. For example, if the vapor is steam, about five vapor separation devices may be used in the top thousand feet, about two in the next thousand feet, and about one device for each additional thousand feet of depth. This spacing limits the temperature losses of vapor inside pipe 15′ to about 50° F., prior to their contact with the incoming feed stream. Closer spacing would further reduce the temperature loss, but his may not be sufficient to compensate for the cost of the equipment.

This vapor-gas separation device, illustrated in FIGS. 6 and 7, functions by venting vapors and gases from inside pipe 15′, directly through the walls of pipe 15′ into the down-flowing feed stream, to condense and return the heat of vaporization to the reaction zone, via the feed stream, at essentially the same temperature at which the vapor was formed. It is unsuitable to the apparatus of FIGS. 1–3 only because of the direction of flow in the central pipe 15.

As in FIGS. 6 and 7, such a vapor trap or separation device may include a pair of tripod mounting brackets 31, supporting a vapor collection bell 32 into which a tube 33 of smaller diameter depends centrally, tube 33 having an inverted U-turn 34 which extends to a vapor outlet 35 in the side of discharge pipe 15′. An annular, conical deflecting plate 36 is suspended below the lower end of vapor collection bell 32, as by rods 37. As will be evident, surges of vapor and gases moving upwardly within discharge pipe 15′ will be directed toward vapor collection bell 32 by deflecting plate 36 and tend to collect inside the bell. Driven by unbalanced hydrostatic pressure, such vapor will pass upwardly through tube 33 and around the U-turn 34 for discharge into the incoming feed moving downwardly along the outside of discharge pipe 15′. After a surge of the vapor-gas mixture has passed through tube 33, the hydrostatic pressure balance will be restored and there will be no tendency for the product liquid, inside pipe 15′, to pass through the tube 33 into the feed liquid; the two streams will be further isolated by permanent gases and uncondensed vapor that tends to remain trapped in U-turn 34 after each surge of the vapor-gas mixture through tube 33. Thus, this construction prevents contamination of the product by the feed and substantially prevents the transfer of product liquid to the feed stream, but it conserves the heat of vaporization which would be otherwise thermally degraded or lost as described above. The gas cushion provided by the downward extension of tube 33 inside bell 32 also reduces hydraulic hammer which may occur when mixed liquids and gases encounter sudden reductions in pipe diameter.

In FIG. 4 is also shown a scavenging pump 38, which may be provided to remove, through discharge pipe 39, nonsuspended material which may collect in the bottom of reaction vessel V. Scavenging pump 38 may be driven in any suitable manner, as by air supplied.

For initiating the reaction, the reaction zone and incoming feed may be heated by introducing hot vapor through a pipe 41 which extends downwardly on the rear side of discharge pipe 15′, as shown in FIG. 5; pipe 41 should extend downwardly far enough so that all vapor issuing therefrom is condensed before it reaches the surface. It will be further evident that, if desired, electric heaters or heat exchange coils may be submerged at a suitable depth and utilized to preheat the apparatus in order to initiate the reaction. Such heaters would be mounted on pipe **15'** and the supply cables or pipes clamped thereto by clamps **22**; alternatively, the feed may be preheated in external heaters.

The sparger S is supplied with air, oxygenated air, or other oxygen-containing gas, in this example involving waste stream treatment, through air pipe **19** which, along with other piping extending downwardly along discharge pipe **15'**, is attached thereto by clamps **22**, which also clamp support cable **21**. Cable **21** may extend to near the bottom of pipe **15'**, being sealed in a gastight manner where it passes through the top of each float bell F. As in the previous embodiment, there may be one or more float bells F which are substantially the same in construction. Sparger S of FIG. **4** may be similar to the sparger S of FIG. **3**, as shown; however, other sparger constructions which produce minute gas bubbles of large aggregate surface area will be equally suitable.

Air or other gas may be removed from float bell F by pipe **23** which connects with the inside of the conical top **26** and extends upwardly along pipe **15'** to a point adjacent the upper end of the discharge pipe. Each of the pipes, which extend below the upper float bell F and other float bells, as well as cable **21**, pass through the conical top **26** of each float bell F and downwardly along pipe **15'** to the desired position. Additional piping includes pipes **42** and **42'** for supplying gas to gas lift pumps at spaced locations, some above that float bell used to supply gas for pumping, within discharge pipe **15'**. Pipes **23** and **24** may supply gas to the inside of the respective float bell F while the apparatus is being assembled or during idle periods in order to maintain buoyancy.

It will be noted that, in general, the incoming feed moves downwardly past the discharge pipe **15'** for several thousand feet to the reaction zone, normally providing ample time for the incoming feed to be heated by the discharge liquid moving upwardly inside discharge pipe **15'**. This countercurrent manner of heat exchange between inflowing and outflowing streams has the same advantages described previously in connection with FIG. **1**; it maintains reaction zone temperature and allows a reaction to proceed spontaneously after originally being started. In this connection, extra combustible material may be added to those streams containing very small amounts of combustibles, but such additions will not ordinarily be required because the heat loss from the apparatus is inherently very small. Excess heat may develop in the apparatus and this situation can be controlled either by diluting the feed with the product stream or by withdrawing vapor, such as steam, through the float bell vent pipes **23** or **24**.

The modification of the apparatus illustrated in FIG. **8** is particularly adapted to be used for concurrent distillation and generation of steam for power purposes; thus, ocean brines or waste streams, for example, can be distilled in conjunction with generation of electricity. Most of the advantages previously listed appear in combination in this embodiment, but the heat conservation advantage is exchanged for a power generation advantage.

The apparatus of FIG. **8** is similar to that of FIG. **4** in that it includes a pressure vessel V installed in a well **9** in the earth **10** and set in concrete **11**, but with a plug **12'** at the lower end being inclined for readier collection and removal of sediment, such as fly ash, and concentrated brine, by a pump **75** which is operated by gas supplied through a pipe **76** and discharging through a pipe **77**, which may be supported by a cable **21'**.

Salt water, waste streams or water from other sources is fed into the upper end of the reaction vessel through an inlet pipe **16'**, while steam passes upwardly through a central steam discharge pipe **78**, which is supported by cable **21** and is provided with insulation **79** extending upwardly from a flotation bell F and also downwardly within flotation bell F to the upper end of a reaction bell R'. Reaction bell R' of FIG. **8** thus has a conical top **60**, a cylindrical skirt **61** having apertures **62** for inflow of the water solution to be evaporated, as well as an air or oxygenated air manifold **66** and tuyeres **67**. Air or oxygenated air for combustion is supplied through a pipe **63'** which extends downwardly alongside steampipe **78**, within insulation **79** for supporting purposes, through float bell F and then outside reaction bell R' to manifold **66**. Fuel is supplied through a pipe **80** which extends downwardly alongside steampipe **78**, within insulation **79** for support, through float bell F and then through the top of reaction bell R' to a point near the lower end thereof.

Relatively large pieces of solid fuel, such as coal, will fall by gravity down through the water in pipe **80**, to the combustion zone inside reaction bell R'. Alternatively, fuel slurries or liquid fuels may be poured down pipe **80**. A mesh grid **81** at the lower end of reaction bell R' prevents large pieces of fuel from falling out of the combustion zone, but permits fuel ash and brine concentrate to fall downward for removal by pump **75**, since coal ash does not melt and agglomerate at flameless combustion temperatures, near 600° F., as it does at conventional combustion temperatures. From the reaction zone in reaction bell R', steam mixed with combustion gases passes upwardly through pipe **78** to a turbine or other power generation device. Since the gaseous products of combustion are mixed with steam at the temperature and pressure existing in the reaction zone, the mixture can be utilized in operating a turbine or the like.

As in FIG. **9**, the steam-gas discharge pipe **78** may extend to a turbine **82** driving a generator **83** and other equipment, not shown, such as air compressors, as desired. Exhaust line **84** from the turbine leads to a spray condenser **85**, which provides the low exhaust temperature necessary for efficient power production. Condenser **85** is equipped in its upper end with a water spray device **86**, the feedpipe to which is surrounded by an annular vent **87**, so that noncondensable gases may be discharged to the atmosphere. Inlet **88** to condenser **85** from turbine exhaust pipe **84** is preferably tangentially located, to produce a circular, swirling action of the steam to engage the water spray. The spray device supplies fresh water previously collected and cooled, as in a pond or reservoir; while the steam condensed by the spray is mixed with water from the spray and collected in though **89** or other suitable receptacle, or recycled to the cooling pond. Contrary to conventional steam plants, the fresh water collected from the turbine exhaust need not be recycled to produce more steam; it is therefore a valuable byproduct of power generation.

In the foregoing embodiments, liquids have been used to provide hydrostatic pressures. But, as mentioned previously, fluidized solids have many of the same hydraulic characteristics as liquids and may therefore be used to provide hydrostatic pressures. The fluidizing agent may be a liquid or gas, for instance, supplied through a central pipe, such as pipe **15** of FIG. **3**. The solids and the fluidizing agents may be chemically reactive or inert or mixtures of the same.

For example, the embodiment of FIG. **3** may be utilized to produce gas from coal when filled with powdered coal which is fluidized by steam or oxygenated steam. Reactive solids, such as calcined dolomites for carbon dioxide absorption, may also be added to the coal. The gaseous reaction products, such as methane or hydrogen and carbon monoxide mixtures, would then collect in bell F at elevated pressures. Nongaseous materials may be removed either from the top of vessel V or by means of a gas lift pump communicating with the bottom of the vessel. Other chemical reactions, such as hydrogenation of oil sands or oil shales, which involve chemical reaction of fluidized solids have previously been described. The apparatus is also particularly suitable for those reforming operations in petroleum refining which utilize fluidized catalysts under pressure.

The preceding embodiments illustrate the invention but do not comprise its entire scope. The invention is, generically, a method and apparatus which provides intimate contact and/or promotion of chemical reactions among solids, liquids and gases, in any desired combination, at elevated pressures that are obtained from substantial depths of liquids or fluidized solids, as well as at desired temperatures. This operation is fundamentally different from conventional apparatus in that, in this invention, pressures are continuously graduated between atmospheric pressure and the reaction zone pressure; all streams, passing through the reaction zone, pass through this continuous gradient in both directions. In contrast, conventional apparatus utilizes a container wall to establish a large pressure discontinuity where atmospheric pressure abruptly changes to reaction zone pressures; all streams passing through the reaction zone in a conventional pressure vessel must cross this discontinuity in both directions. There are further distinctions in that gravity maintains the continuous pressure gradient and hence the reaction zone pressure in this invention and in that solids pass easily through the liquids or fluidized solids. The combination of advantages listed previously all stem primarily from the continuous pressure gradient and the other factors just described. The advantages are not obtainable in conventional reaction vessels primarily because of the pressure discontinuity, just described, that is characteristic of such vessels.

It will be understood that certain features of this invention may be utilized in distillation processes and apparatus and in electrolytic processes and apparatus, as well as others.

Although several embodiments of this invention have been illustrated and described and certain variations therein indicated, it will be understood that other embodiments may exist and that various changes may be made therein, all without departing from the spirit and scope of this invention.

What is claimed is:

1. A method of carrying out a chemical process at an elevated pressure and involving a liquid and both a gaseous reactant and a gaseous resultant of the reaction, which comprises:
effecting a contact of the elements involved, including said liquid, within a pressure zone which is pressurized by a depth of said liquid sufficient to produce the elevated pressure, said pressure zone being within a generally vertical, laterally confined space;
separately introducing said gaseous reactant to said pressure zone;
conveying a fluid between said pressure zone and the upper end of said confined space through a tubular conduit extending downwardly in said space to said pressure zone;
collecting said gaseous resultant of the reaction within a laterally confined member attached to said conduit to utilize the buoyancy of said gaseous resultant of the reaction to support at least a portion of the weight of said conduit; and
withdrawing said gaseous resultant from said member at a controlled rate.

2. A method as defined in claim 1, wherein:
said liquid comprises a fluidized stream of solids acting as a liquid.

3. A method as defined in claim 1, wherein:
said gaseous reactant is supplied to said pressure zone at a pressure slightly above that at the point of introduction;
said liquid flows downwardly outside said conduit;
a liquid resultant of the reaction flows upwardly within said conduit; and
a gaseous product separating from said liquid flowing upwardly in said conduit, due to diminution in pressure above said pressure zone, is collected and transferred to said liquid outside said conduit.

4. Apparatus for carrying out a chemical process at an elevated pressure and involving a liquid, comprising:
means defining a vertically elongated, laterally enclosed space;
means for introducing said liquid adjacent the top of said space means, so that the desired pressure is produced by the hydrostatic head of said liquid in a lower zone of said space;
a pipe extending downwardly within said space to the lower
separate means for introducing a gaseous reactant to said lower zone;
at least one hollow, depending float bell associated with said pipe for receiving gas, as by collecting gaseous resultants of reaction therein, to provide buoyancy to assist in supporting said pipe; and
means for supplying gas to or withdrawing gases from said float bell.

5. Apparatus as defined in claim 4, wherein said means defining said space comprises:
a bore extending downwardly into the earth; and
a pressure vessel within said bore.

b. Apparatus as defined in claim 4, wherein:
said downwardly extending pipe conveys said liquid to the lower portion of said pressure zone.

7. Apparatus as defined in claim 4, wherein:
said downwardly extending pipe conveys a liquid reaction product upwardly, said liquid moving downwardly outside said pipe.

8. Apparatus as defined in claim 7, including:
means in said pipe for trapping vapors formed by diminution of pressure in said pipe and transferring the same to the liquid moving downwardly outside said pipe.

9. Apparatus as defined in claim 4, wherein:
said downwardly extending pipe conveys said liquid downwardly and extends below the lowermost float bell;
said liquid is water carrying oxidizable material; and
said gaseous reactant is an oxygen-containing gas supplied to said pressure zone below the lowermost float bell but above the lower end of said pipe.

10. Apparatus as defined in claim 4, wherein:
said liquid carries oxidizable material;
said downwardly extending pipe conveys a liquid product upwardly and extends below the lowermost float bell; and including
said gaseous reactant is an oxygen-containing gas supplied to said pressure zone below the lowermost float bell.

11. Apparatus as defined in claim 4, wherein:
said float bell acts as a hollow reaction bell having a depending sidewall associated with said pipe and disposed in said reaction zone, said liquid containing dissolved solids and carrying solid fuel particles; and
said gaseous reactant is an oxygen-containing

12. Apparatus as defined in claim 4, wherein said liquid is a waste liquid containing combustible material, said apparatus including:
a hollow reaction and float bell having a depending sidewall and a closed upper end surrounding said pipe and attached thereto in said lower zone;
a supporting cable extending downwardly alongside said pipe to said bell;
a sparger surrounding said pipe below said bell;
means for supplying an oxygen-containing gas to said sparger, said oxygen-containing gas flowing upwardly to said bell for reaction with said combustible material to produce gaseous products;
means extending downwardly alongside said central pipe and supported thereby for withdrawing gaseous products from said bell;
means for supplying said waste liquid to the upper end of one of said central pipe and said space means; and
means for withdrawing the treated waste liquid from the upper end of the other of said central pipe and said space means.

13. Apparatus as defined in claim 4, for producing steam, including:
an upright, elongated pressure vessel enclosing said space and having a closed lower end;
said pipe being an insulated steam discharge pipe extending downwardly within and in spaced relation to said pressure vessel;
said float bell being a hollow reaction bell having a depend-

means for supplying water containing fuel particles into the upper end of said pressure vessel;

a series of apertures in said sidewall of said reaction bell at a position spaced above the lower end thereof and through which said water and fuel particles may pass; and

said gaseous reactant being an oxygen-containing gas supplied to the inside of said reaction bell at a position below said apertures.

14. Apparatus as defined in claim **13**, including:

a float bell having a depending sidewall and surrounding said pipe and connected thereto above said reaction bell, said float bell collecting gases and providing, through buoyancy, at least partial support of said pipe;

a screen across the lower end of said reaction bell; and

pumping means for removing liquid and unreacted solids from a position below the lower end of said reaction bell.

15. Apparatus as defined in claim **4**, including:

airlift pumping means adjacent the lower end of said reaction zone for removing sediment collecting in said lower end of said reaction zone; and

means for supplying air to said airlift pumping means.

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,606,999 Dated September 21, 1971

Inventor(s) Harold L. Lawless

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 59, "example" should read --examples--; line 72, "rmeain" should read --remain--. Column 2, line 4, "remain" should read --pump--; line 12, "orifices" should read --orifice--. Column 3, line 1, "feed" should read --feet--; line 49, before "vertically", --a-- should be inserted. Column 4, line 40, "b" should read --be--; line 46, "alone" should read --zone--. Column 5, line 29, after ";" --and-- should be inserted; line 38, before "elevated", --at-- should be inserted. Column 6, lines 7 and 8, "may be....buoyancy" should read --vessel--. Column 8, line 69, --through pipe 40-- should be inserted after "supplied". Column 9, line 73, "thus" should be cancelled. Column 10, line 41, "though" should read --trough--. Column 12, line 13, the claim number should be changed from "b." to --6--; line 44 (claim 11), --gas supplied to said reaction bell-- should be added.

Signed and sealed this 14th day of March 1972.

(SEAL)
Attest:

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