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3,371,713

SUBMERGED COMBUSTION IN WELLS

Filed July 25, 1966

3 Sheets-Sheet 1

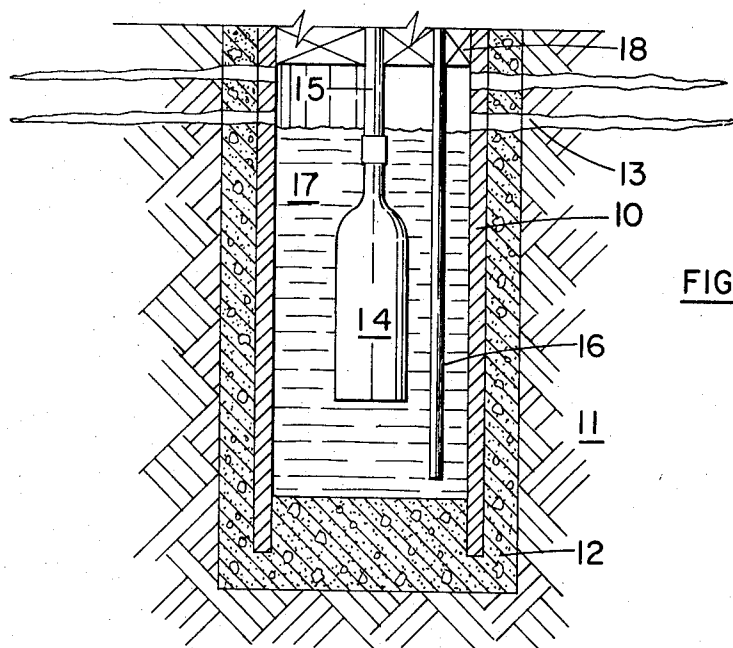


FIG. 1

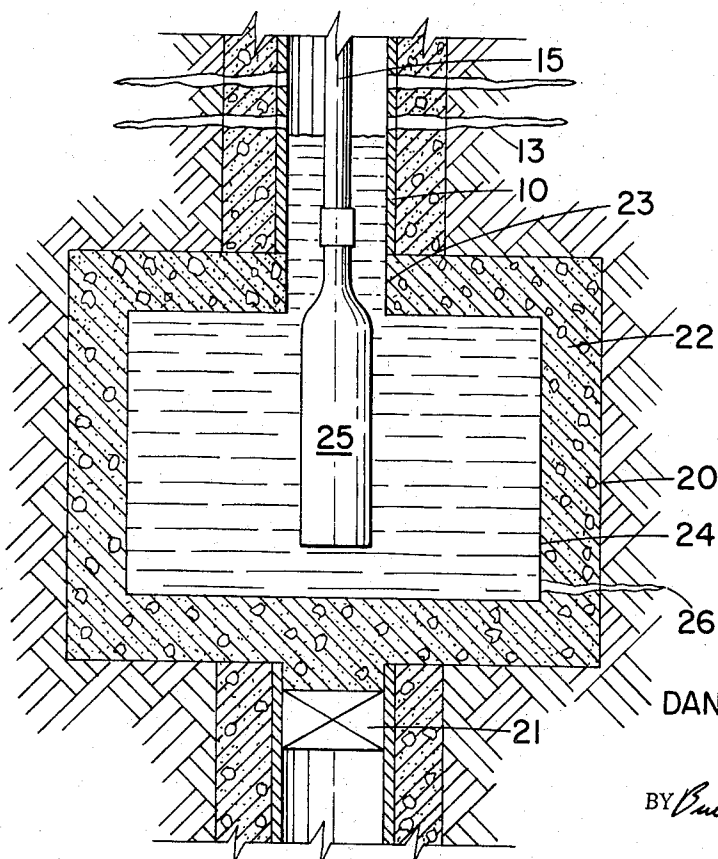


FIG. 2

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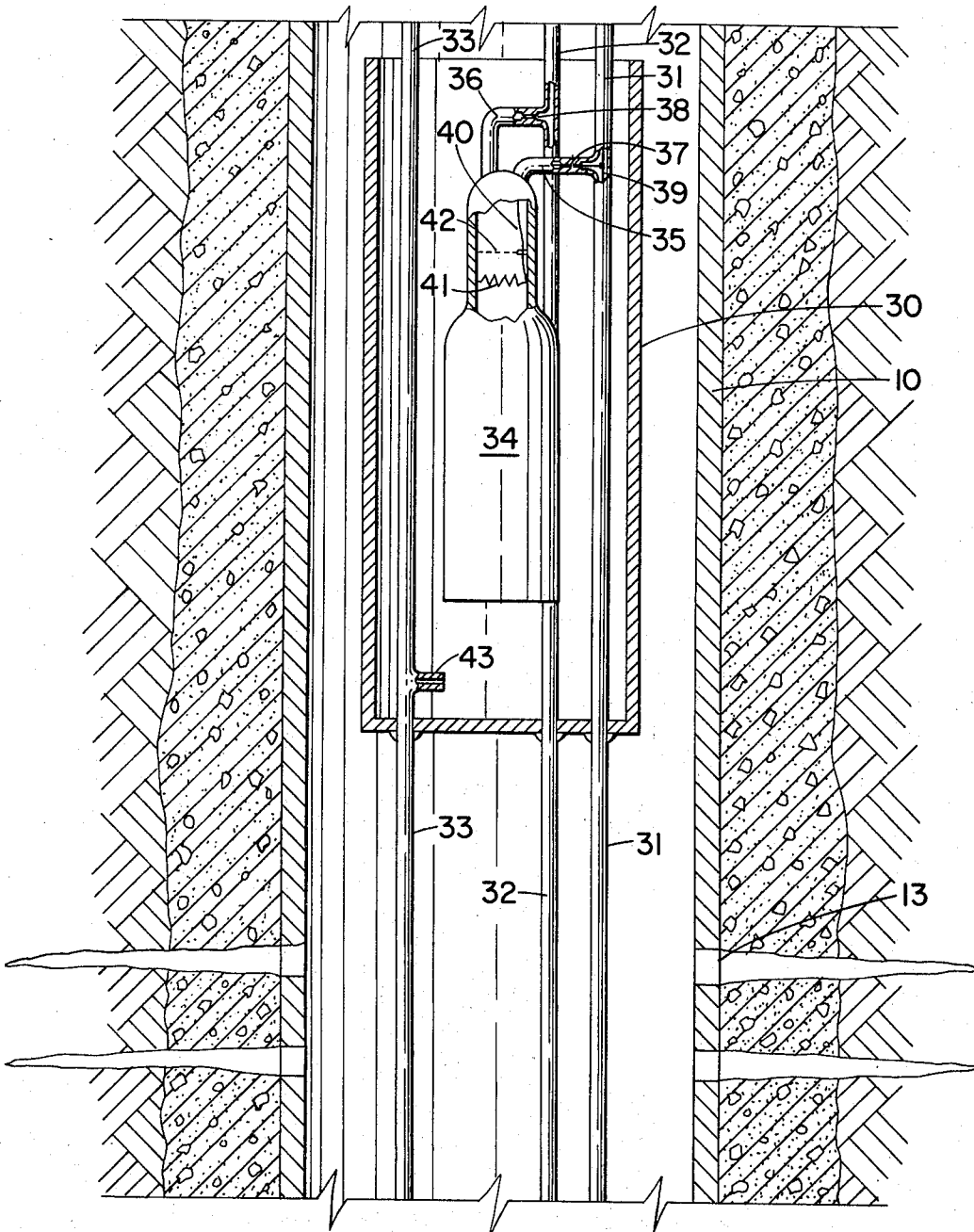


FIG. 3

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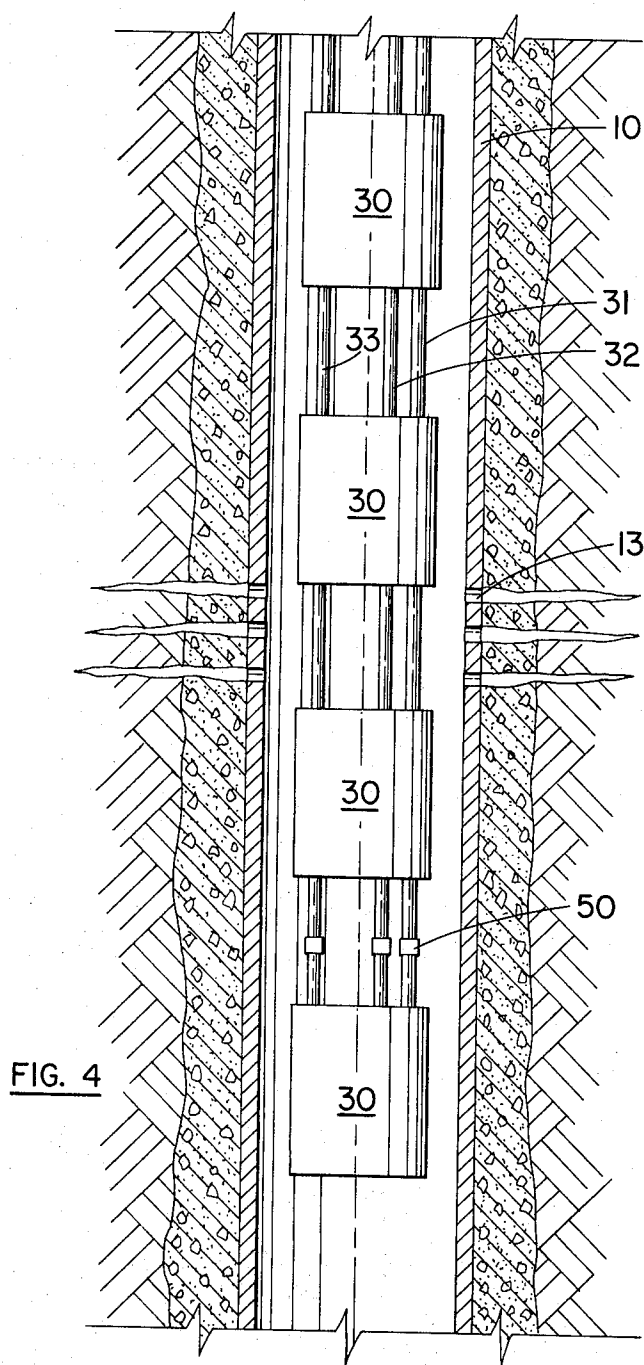
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SUBMERGED COMBUSTION IN WELLS

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This invention relates to steam flooding of oil-bearing formations. More particularly, it relates to a method and apparatus for generating the steam.

It has been proposed to heat oil-bearing formations to improve oil production by injecting steam into the formation. Ordinarily, steam is generated at the top of a well penetrating the oil-bearing formation, the steam then being injected down tubing in the well to the formation. Loss of heat from the steam as it travels to the bottom of a well can be expensive. In addition, such loss of heat causes many other problems such as expansion of well casing and the like. To overcome some of these difficulties use of a bottom hole heater has been proposed. The low heat output of heaters which can be lowered into most well casing has prevented commercial use of such heaters for generating steam, however.

With the above problems in mind, an object of this invention is to provide a method and apparatus for steaming oil-bearing formations, the method and apparatus avoiding heat losses due to travel of the steam down the well. A more specific object is to provide a method and apparatus for generating a large amount of heat at the bottom of a well. Still other objects will be apparent from the following description and claims.

In general, I accomplish the objects of my invention by the use of submerged combustion in a well to generate steam.

My invention will be better understood from the drawing in which FIGURE 1 is a view, partially in cross-section, of the bottom of a well arranged for use of a submerged combustion burner to generate steam. FIGURE 2 is a view, partially in cross-section, of an arrangement for using a large burner in an enlarged chamber in a well. FIGURE 3 is a view, partly in cross-section, of a submerged combustion burner in a container, the burner and container being connected for lowering together into a well. FIGURE 4 is a view, partly in cross-section, of a plurality of the burner and container units of FIGURE 3 in axial alignment within a well.

Considering the figures of the drawing in more detail, in FIGURE 1 a casing 10 is cemented into a formation 11 by cement 12. The bottom of the casing is also filled with cement. The casing and cement are perforated at 13. A burner 14 is lowered into the section of the well below the perforations. The burner is lowered and supported on a conduit 15 which supplies a combustible gas such as methane and an oxygen-containing gas such as air to the burner. A second conduit 16 supplies water 17 to the well below the perforations. A packer 18 surrounds conduits 15 and 16 and separates the portion of the well below the packer from the portion above the packer.

In operation, cementing of the casing in the bottom of the well and leaving the bottom of the casing cemented forms a substantially impermeable container in the bottom of the well to hold water. The burner is completely submerged in the water. This is important since it has been found that, by submerging the burner, up to about 10 times as much heat can be generated by the burner as when the burner is not submerged. This is not new, being well known in the submerged combustion art.

The packer is not essential but is preferred to prevent steam from rising up the well, condensing and running back as in a reflux condenser. The packer avoids this heat loss.

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When the burner is in place and the packer has been set, a combustible mixture of natural gas and air is pumped down conduit 15 and is ignited by a hot wire, spark plug, or the like, as shown in more detail in FIGURE 3. At the same time, water is pumped into the bottom of the well through conduit 16. Combustion gases from the burner rise up through the water around the burner and provide violent agitation which cools the burner. The combustion gases also become finely divided and transfer their heat to the water which causes the water to evaporate and form steam. The combined combustion gases, steam and some liquid water then flow through perforations 13 into the formation to be steam flooded.

The amount of water pumped into the container is important for two reasons. First, the burner must not be permitted to evaporate more water than is added or the water level falls below the top of the burner. When this happens, insufficient cooling is provided and the burner deteriorates rapidly. Second, it is rarely possible to use water of high purity for steam generation in the field. If water is added continuously and only steam is removed, any salts in the water are rapidly concentrated in the remaining liquid water and eventually precipitate in the container. It is important, therefore, that more water be introduced than can be evaporated by the burner. Thus, some of the water must leave the container as liquid water with the salt in solution. This excess water may leave as mist entrained in the gases or it may leave by simply flowing into the lower perforations as hot liquid water. It is preferred that from about 20 percent to about 100 percent excess water be used. For most efficient removal of salt from the container, it is preferred that the new water be introduced at the bottom of the container. This is not strictly necessary, however, since the violent agitation of the water by the combustion gases provides effective mixing of the water wherever it is added.

It should be noted that pressures in the range of 1,000 to 1,500 pounds per square inch may be desirable for obtaining adequate rates of injection of steam into the formations. This means operating at temperatures in the range of 500° to 600° F. Even higher pressures and temperatures may sometimes be required. Most cements weaken at least slowly at such temperatures. Therefore, it may be desirable to use in the well a high temperature cement such as described in U.S. Patents 3,180,748 or 2,805,719, for example, to withstand these temperatures.

The amount of heat which can be generated in a submerged combustion burner depends to a large degree on the cooling of the burner surface. When used for evaporating water, for example, a burner 3 inches in diameter and about 15 or 20 inches long can generate up to about 400,000 or 500,000 British thermal units (B.t.u.) per hour without excessive deterioration of the burner. A burner 6 inches in diameter and 30 inches long can be used to generate over a million B.t.u. per hour. Since the well diameter is rather small in most cases, and since adequate space must be allowed around the burner for the combustion gases to mix with water, the burner size is limited in most wells. Steam generation by a single burner in most wells will be correspondingly limited even if submerged combustion is employed.

One possible way to increase steam-generating capacity is shown in FIGURE 2. In this case, casing 10 has been cemented through formation 11 much as in FIGURE 1. In FIGURE 2, however, a cavity 20 has been formed by underreaming, blasting or the like. A bridging plug 21 has been set in the casing below the cavity and the entire cavity has been filled with high temperature cement 22. A hole 23 has been drilled into this cement plug and the plug has been underreamed to form a substantially impermeable cavity 24. The result is an enlarged substantially impermeable container which can be

filled with water. Burner 25 in this arrangement may be only slightly smaller in diameter than the well casing 10. Adequate clearance between the burner and the walls of the enlarged cavity is thus provided for carrying out a submerged combustion capable of generating several million B.t.u. per hour.

It will be noted in FIGURE 2 that no separate conduit is provided for conducting water to cavity 24. Such a conduit may be provided if desired. A packer above the cavity may also be used. In FIGURE 2, however, it is contemplated that the water is simply poured down the annular space between the tubing and casing. A small portion of the water will enter the perforations 13 but almost all of the water will flow past the perforations and will be mixed with the water surrounding the burner by the violent agitation caused by the submerged combustion. At least part of the water may even be introduced down conduit 15 with the air and gas.

If desired, a small bleed hole 26 can be formed near the bottom of cavity 24 to permit a small stream of water to leak away from the cavity and carry away most of the concentrated salts. The presence of one or more such small drainage holes should not be regarded as destroying the substantially impermeable nature of the container for the water. If such holes are formed, however, it is advisable to determine how much water leaks from these holes by filling the container with water, applying pressure and measuring the rate of fall of the water level. This operation should be conducted without the burner in operation. Then, when the burner is placed in operation, enough water is added to meet the requirements of the leakage rates through the drainage holes, as well as to maintain the container full in spite of evaporation by heat from the burner.

Another arrangement for providing more steam than can be produced by a single small burner is shown in FIGURE 4. In this case, a series of containers 30 is arranged axially along the well inside well casing 10. Each container holds sufficient water to submerge a burner as shown in more detail in FIGURE 3. Air, gas and water are fed to the assembly through lines 31, 32 and 33, respectively. Steam generated by the assembly, together with combustion gases and excess liquid water, are forced through perforations 13 in the well casing and on into the surrounding formation.

In FIGURE 3 one of the container-burner units of FIGURE 4 is shown in more detail. The container 30 is inside well casing 10. Air, gas and water conduits 31, 32 and 33 enter the top of container 30 and pass through the bottom of the container to the next unit below. The bottom of the container is welded to the conduits so the conduits support the container in the well. Conduits 31 and 32 are connected to the top of burner 34 through side connections 35 and 36. These side connections include orifices 37 and 38 which permit only a part of the air and gas in conduits 31 and 32 to enter each burner. An insulated wire 39 passes down through one conduit and has a branch lead 40 to a heater element 41 which is used to ignite the burner. An arrangement such as that shown in U.S. Patent 2,506,853 may be used to avoid running a permanent wire to the surface through the conduit.

A flame guard 42 is provided above the heater to avoid flashback from the combustion zone. This is particularly desirable if the air and gas are pre-mixed at the top of the well and sent down to the burner through a single conduit as shown in FIGURES 1 and 2.

A portion of the water stream in conduit 33 is permitted to enter container 34 through orifice 43. Conduit 33 helps support container 30 but does not support burner 34 in the arrangement shown in FIGURE 3. The conduit 33 can, however, also be mechanically attached to burner 34 to assist in connecting the burner and container into an assembly which can be lowered into the well as a unit.

In the bottom unit shown in FIGURE 4 the conduits end at the bottom of the container. It is possible, of course, for the burner and container to be connected by other means so the conduits can terminate above the bottom of the container. It is also possible for such a unit to be used alone in a well in place of the arrangement shown in FIGURE 1. While conduits 31, 32 and 33 have been shown passing through container 30, it will be obvious that they can also be placed outside the container, mechanical connections between the conduits, container and burner being provided to connect the burner and container into an assembled unit. If desired, coupling elements shown schematically as 50 in FIGURE 4 can be used to permit disassembly of the series of containers for easy transport and handling.

The size and shape of the burner may be as shown in U.S. Patent 2,159,759, for example, or may be specially designed for high pressures such as that shown in U.S. Patent 2,668,592.

My invention will be better understood from the following example. A well is 1,520 feet deep. It has 7-inch casing cemented at the bottom. The casing is perforated over a 20-foot interval from 1,440 feet to 1,460 feet. An assembly of 6 units, as shown in FIGURES 3 and 4, is lowered into the well until the bottom unit is at about 1,480 feet. Each container is 5 inches in diameter and 30 inches long. Each burner is 3 inches in diameter and 20 inches long. All containers are filled with water. Injection of about 3,000 cubic feet of natural gas per hour and about 40,000 cubic feet of air per hour is started. The burners are ignited and injection of about 12 barrels of water per hour is begun (42 U.S. gallons per barrel). This provides about 50 percent more water than will be evaporated by the burners insuring that some liquid water will remain to carry salts into the formation in solution in the water. The extra water also makes certain that the containers remain filled so the burners remain submerged. It will be clear that if the water used is substantially free of dissolved salts, the need for excess water is reduced.

After 15 days of operation, a little over 1,000 million B.t.u.'s of heat have been added to the formation. At this time, injection of air, gas and water is interrupted and the well is shut in and allowed to soak for 5 days. The well pressure is then released and the well is allowed to produce oil from the heated formation.

Many variations and alternates are possible. For example, rather than producing oil from the well into which the steam is injected, the heat can be forced from this well to another producing well by steam, gas or water in a manner previously known in the art of heating oil-bearing reservoirs. Other means of forming a substantially impermeable container can be used. For example, a bridging plug may be set in the casing below the zone to be steam flooded and a batch of high temperature cement can be dumped on top of the bridging plug to form a permanent bridge in the casing.

Reference has been made to use of gas as the combustible fluid. A gas such as methane is certainly the preferred fuel. It will be understood, however, that liquids such as gasoline or fuel oil may also be used as the combustible fluid.

Other variations and alternates to the examples described above will be apparent to those skilled in the art. Therefore, I do not wish to be limited to the examples described but only by the following claims.

I claim:

1. A method for steam flooding an underground formation penetrated by a well comprising:

providing in said well a container with a closed bottom, at least the lower portion of said container being substantially impermeable,

providing a burner placed entirely within the substantially impermeable portion of said container,

supplying a combustible fluid and an oxygen-containing

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gas to said burner, said fluid and gas being supplied in a combustible ratio, igniting the combustible mixture in the burner, introducing into said container water in an amount greater than the amount evaporated by combustion of said combustible mixture, and maintaining in said well a pressure sufficient to force the resulting steam, water and combustion products into said formation.

2. The method of claim 1 in which said container is in said well and said burner is lowered into said container.

3. The method of claim 1 in which said container is provided by enlarging a section of said well, below the zone to be steam flooded, to a diameter greater than the average well diameter at that level, sealing the bottom of said enlarged section and sealing the sides of said enlarged section to a height greater than the length of said burner.

4. The method of claim 1 in which said container is provided by forming a bridge in said well at a level below the zone to be steam flooded.

5. The method of claim 1 in which said container is attached to said burner and is lowered into said well with said burner.

6. The method of claim 1 in which said burner is lowered into said well on the conduit which supplies at least one of the combustible fluid, oxygen-containing gas and water to the submerged combustion operation in said container.

7. The method of claim 1 in which said combustible fluid is substantially methane and said oxygen-containing gas is air.

8. The method of claim 1 in which the amount of water supplied is between about 20 percent and about 100 percent greater than the amount evaporated by combustion of said gases.

9. The method of claim 1 in which a packer is set in said well above said formation to prevent loss of steam up said well.

10. Apparatus for generating steam in a well for steam flooding a formation penetrated by said well, said apparatus comprising:

a container in said well, at least the bottom portion of said container being substantially impermeable,

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a burner entirely within the substantially impermeable portion of said container, means extending from the top of said well for supplying a combustible fluid and an oxygen-containing gas to said burner,

means extending from the top of said well for supplying more than sufficient water to said container to maintain at least the impermeable portion of said container full when said burner is in operation, and means for igniting the mixture of combustible fluid and oxygen-containing gas in said burner.

11. The apparatus of claim 10 in which the water-supplying means is a conduit extending to a level below the bottom of said burner.

12. The apparatus of claim 10 in which said container is attached to the burner in a manner permitting the two to be lowered into the well together.

13. The apparatus of claim 10 in which a plurality of burners in containers are arranged in axial alignment in said well.

14. The apparatus of claim 10 including means to seal the cross-section of the well above said burner and container.

15. The apparatus of claim 10 in which said means for supplying a combustible fluid and an oxygen-containing gas comprises at least one conduit extending from the top of said well to said burner.

16. The apparatus of claim 10 including means to discharge from the lower portion of said container controlled volumes of water.

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