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[54] GAS CAP STIMULATION FOR OIL RECOVERY

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[52] **U.S. Cl.** **166/261,** 166/272

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[58] **Field of Search** 166/261, 256, 272, 260

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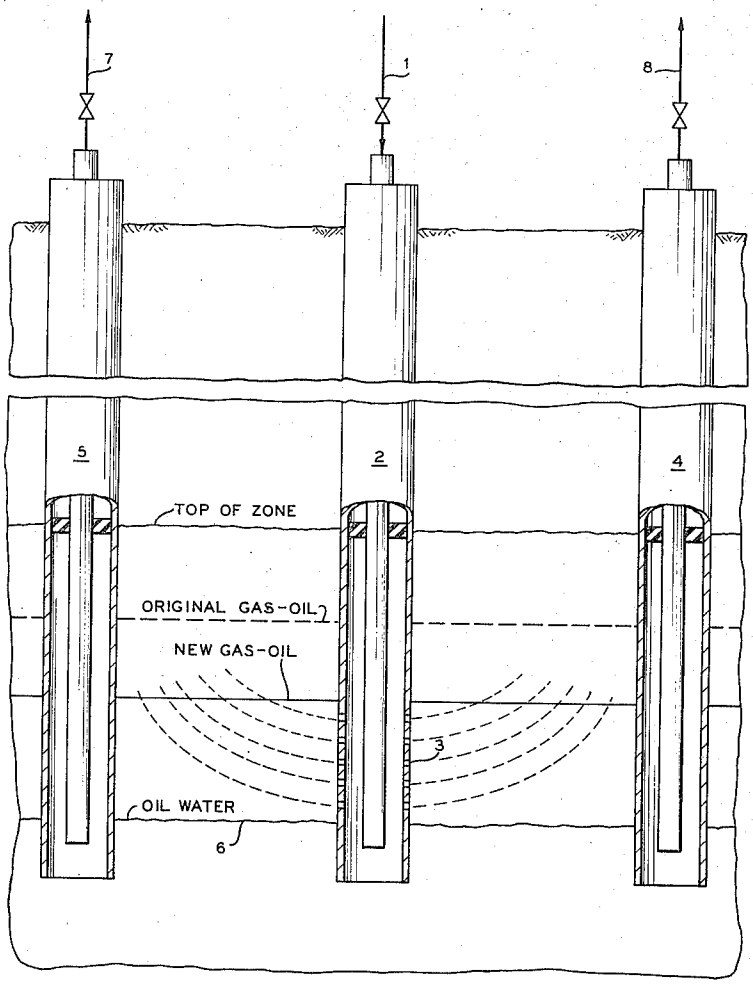
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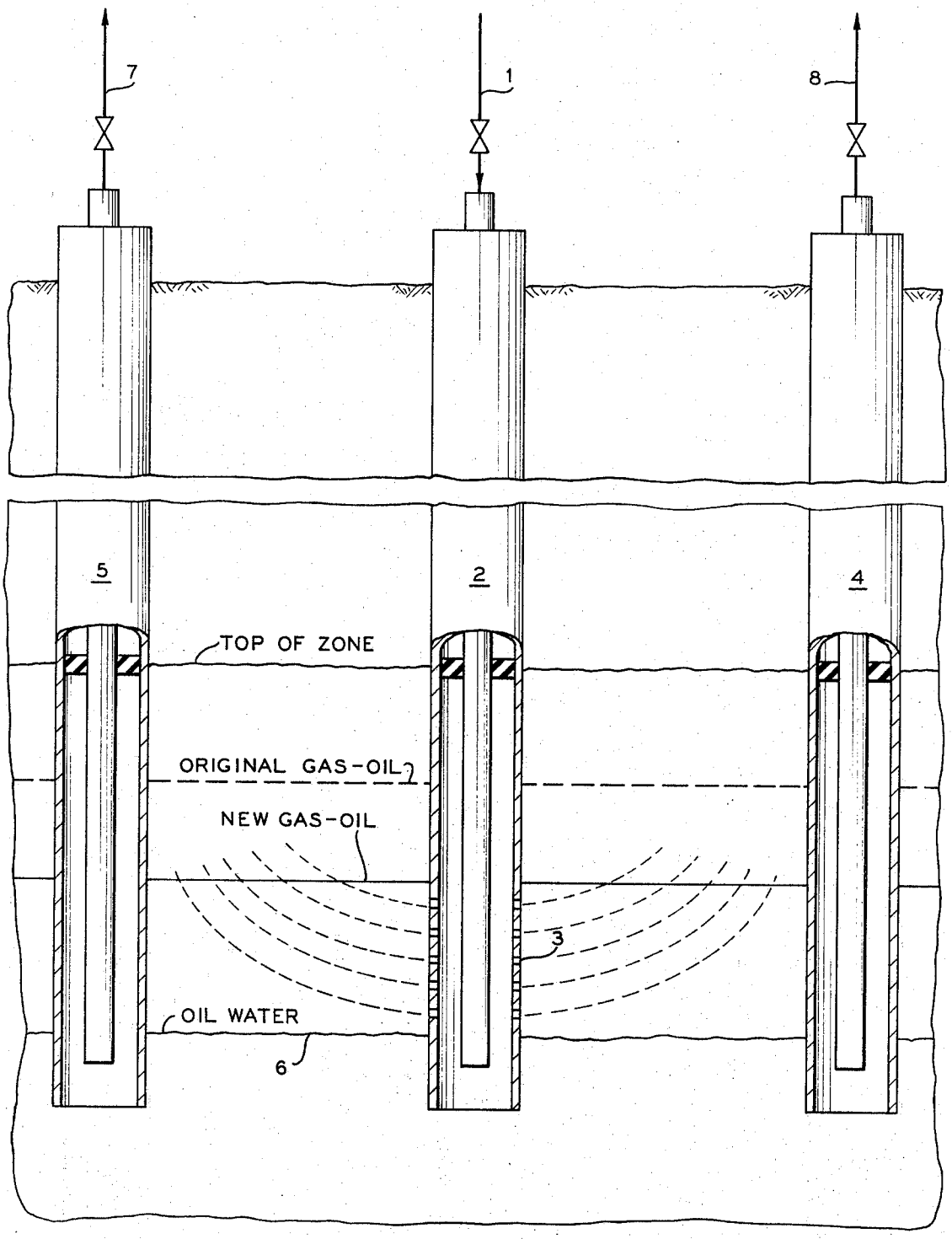
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[57] **ABSTRACT**

A hot fluid, e.g., steam, combustion gas, CO_2, natural gas, etc., is injected preferably into the gas cap above an oil interval or formation, followed by sufficient water to partially seal the treated formation against fingering and channeling of air later injected, then injecting air to cause spontaneous ignition and in situ combustion of gas and/or residual oil in the gas cap creating heat and pressure whereby viscosity of oil is reduced and oil is moved in improved manner toward producing wells.

4 Claims, 1 Drawing Figure




7
1
8
5
2
4
TOP OF ZONE
ORIGINAL GAS-OIL
NEW GAS-OIL
3
OIL WATER
6

GAS CAP STIMULATION FOR OIL RECOVERY

This invention relates to the recovery of oil from a formation. In one of its aspects, it relates to the stimulation of a gas cap above an oil interval or formation to accelerate the rate of oil production from the oil column. In another of its aspects, the invention relates to a multi-step method of generating heat and pressure in a gas cap above an oil column involving spontaneous ignition and combustion at least in the gas cap.

In one of its concepts, the invention provides a method for heating and pressurizing a gas cap adjacent to an oil column or interval by heating the gas cap portion of the formation by injecting a hot fluid such as steam, combustion gases, carbon dioxide, natural gas, etc., into the gas cap until it has been sufficiently heated to permit spontaneous ignition and consequent combustion upon injection later of air or other combustion supporting fluid, injecting water which can be heated, as desired, into the gas cap in a quantity sufficient to act as a barrier to retain air later injected there into in the gas cap, and then injecting air in quantities sufficient to cause spontaneous ignition and to sustain combustion in the gas cap for a time sufficient to increase temperature of the oil column, lowering the viscosity of the oil, and to create a pressure above the oil column thus causing increased oil flow by gravity drainage toward the producing well or wells.

The secondary recovery of oil from formations is becoming increasingly necessary in view of the shortages of crude oil in this country.

It is known that the usual initial production from an oil formation becomes unattractive after a number of years and that this occurs at a time when considerable oil is remaining in the formation. Secondary recovery methods are known.

It is well known and recognized by those experienced in thermal recovery that in either a combustion drive or direct steam drive that additional oil can be recovered from many heavy oil reservoirs. In these processes it was desirable to confine the injected fluid in the zone containing the oil to be displaced, and the additional oil to be recovered is pushed somewhat like a piston to offset producing wells. Examples of patents teaching several thermal recovery methods are U.S. Pat. Nos. 3,425,492 and 3,171,479. Generally, gas caps above an oil column were considered a significant process disadvantage because the injected fluids would channel through these zones.

With the novel process of this invention, I take advantage of the presence of the gas cap and use it to facilitate the placement of a hot zone by steam injection above an oil column thus heating a larger areal extent of the oil zone. This heating can be augmented by in situ combustion along or above the gas cap-oil column interface as disclosed herein.

I have conceived an improved secondary method of recovery of oil from a formation particularly applicable to a formation surmounted by a gas cap, i.e., a portion of formation which contains mobile gas and which may contain a small amount of immobile residual oil. The "gas cap" is one which may be under some natural pressure or it may be one in which actually there is a vacuum pressure caused by pumping of oil from the formation and from withdrawing gas from the reservoir with vacuum pumps.

It is an object of this invention to provide a secondary oil recovery method. It is another object of this invention to provide a method for the stimulation of a gas cap in a formation containing oil. It is a further object of this invention to provide a gas cap stimulation method in which channeling or fingering of injected combustion sustaining fluid, e.g., air or oxygen is prevented and/or restricted.

Other aspects, concepts, objects and the several advantages of the invention are apparent from a study of this disclosure, the drawing and the appended claims.

According to the present invention, there is provided a multi-step method of stimulating an oil containing formation by injecting, preferably into a gas cap surmounting the same, sufficient steam to heat the gas cap and to cause propagation of a heat front into oil column so that upon subsequent injection of air auto-ignition will occur and combustion can be sustained, injecting water in an amount sufficient into the heated formation or gas cap to prevent fingering or channeling of later to be injected combustion sustaining fluid, e.g., air, etc., and then injecting air into the now heated and water containing portion of the formation thus to cause the auto-ignition or spontaneous ignition to occur and to sustain combustion to generate heat and pressure to cause the oil in the heated oil column to be of lower viscosity and to move as by gravity drainage and by pressurizing effects toward producing wells.

The following is a more detailed description of the invention which has been applied to a portion of the Smackover Sandstone field in Arkansas.

The invention having been applied to that field it will now be described in connection with that field.

This invention relates to the recovery of oil, especially from an oil formation which has a gap cap above the oil zone. In particular, this invention relates to steam injection into the oil or gas cap as a means for heating the oil and also for building up pressure above the oil zone to force the mobile oil to flow into surrounding production wells. After steam has been injected and the formation, both in the oil zone and gas cap, has been heated, a slug of water is injected which forms a horizontal bank of high water saturation above the oil zone for the next step of air injection.

While the conventional steam drive process appears technically sound, it often is uneconomical since heat consumption or losses are excessive. One way to overcome a major disadvantage of the steam injection process is to follow the high temperature fluid with unheated water to reclaim the sensible heat of the formation from the area where the fluid has removed the recoverable oil and to carry this reclaimed heat to an area which is still unheated. This method is successful in transferring heat from an area where it is no longer useable to an area where it will assist in the recovery process as well as form a bank to prevent fingering or channeling of air which is next injected.

Air is injected following the water slug to the extent that in situ combustion occurs developing high temperatures and combustion gases which will pressure up the formation causing oil below the previously injected water slug to be driven at a higher rate into the producing wells thus aiding the gravity drainage rate. The water slug as noted prevents or retards fingering of the air. Thus channeling of air and combustion gases are prevented and higher reservoir pressures are realized.

The air ignites residual oil which has remained lodged in the gas cap or adjacent to the gas-oil contact. Ignition occurs readily since the temperature is high and only an oxidizing atmosphere is needed to bring about combustion.

After combustion has been carried out, another slug of water is injected to further reduce channneling of the combustion gases and to scavenge heat from the burning zone. The heated water will tend to flow by gravity into the oil column and it reduces the viscosity of the remaining hydrocarbon.

After the second slug of water has been injected into the gas cap, air is injected again to cause a second combustion period to occur.

These steps can be repeated, after which steam can again be injected to give the fire front time to die out. The above steps can again be repeated.

The point at which the injection of steam, water, and air is practiced can be any place in the oil zone or gas cap. It is preferred that the injections be made near the bottom of the oil zone. However, live steam will migrate to the gas cap above the oil column and then channel along the heating oil as it migrates into the top of the oil column at the level of the gas-oil contact. The oil zone is heated by direct contact or by conduction of heat from the heated gas cap.

This invention will create a horizontal thin zone of combustion across the top of the oil zone, the heat and pressure, on top of the oil zone, accelerating gravity drainage.

The Smackover field was discovered during the 1920's and during the initial phases of the production produced 20° API crude oil. The initial reservoir pressure was 1,050 psia. The reservoir temperature was 110°F. It is estimated that originally 100 to 200 cubic feet of gas were in solution in each stock tank barrel of crude oil and that the original formation volume factor of the oil was 1.1. The viscosity of the initial oil at reservoir conditions was about 25 centipoise. By 1930, the bottom hole pressure of the Smackover Field in the Nacatoch Reservoir reduced to about between 5 and 10 psia with essentially no gas in solution. The API gravity reduced to about 19, the oil formation factor was about 1.0. The oil viscosity: 75 centipoise. The reservoir temperature is 110°F at the present time.

The attached FIGURE is a typical cross section of the field, where the present invention is carried out. Initially the top of the Nacatoch formation was at about 1,940 feet below the surface of the ground and the oil/gas interface was at 1,964 feet below the surface of the ground. The oil/water interface was about 2,005 feet in depth. As production continued until about 1970, the oil/gas interface had dropped to about 1,985 feet below the surface of the ground. In other words, the oil/gas interfaced had dropped about 21 feet below its initial discovery point below the surface of the ground. The gas cap had increased appreciably in thickness because of oil production from the oil column. At the start of the present invention, the result of core and log analysis indicated that the water saturation at the start of steam injection averaged about 20 percent in the oil column above the oil-water contact, and increased with depth to about 100 percent below the original oil-water contact.

In carrying out this invention in the Smackover field, steam generators which produce about 45,000 pounds per hour of 100 percent quality steam (at the outlet of the steam generators) are used to inject steam into the formation through the injection well through perforations in the casing with the perforations being into the oil zone, i.e., in the zone between the oil/gas interface and the oil/water interface. The initial steam injection was at a surface pressure of 595 psig at 485°F, but it was found that injection improved until an injection pressure of 390 psig at 446°F is sufficient to maintain injection of 45,000 pounds of steam per hour. The steam while being injected directly into the oil zone, because of its low density, it immediately migrated upwards into the gas zone, or gas cap. Through an observation well, it was determined that the temperature of the zone invaded by live steam rose to about 270°F across the invaded zone as long as steam was injected at the rate of 45,000 pounds per hour.

The following is a general description of the improved formation stimulation or improved thermal recovery process as it can be applied to the aforementioned reservoir, according to the invention.

Steam or other hot fluid, e.g. combustion gases, CO_2, natural gas, etc., is injected into a center well in a 20-acre area through the injection wellbore into Smackover Sandstone. Steam will move preferentially through the gas cap toward the producer wells. Heat is thus conducted into the oil zone underlying the gas cap. The increase in temperature decreases the viscosity of the oil and accelerates the rate of recovery by gravity drainage. Also, the steam causes a pressure gradient between the injection well and offset producing wells, thereby increasing the producing rate to more than that resulting from gravity drainage. After injecting approximately 150,000 million BTU of heat into the formation as steam whose quality is 80 percent, (20 percent water), the steam injection will be moved to another 20-acre pattern. In order to partially or fully maintain the reservoir pressure in the steamed area and to generate additional heat to replace heat losses, in this improved recovery process, an alternate slug injection program of water and air is begun at the original injection well.

A slug of water which can be fresh water or produced brine equal in volume to about 10 percent of the reservoir gas cap pore volume will be injected through the injection well to reduce channeling and fingering of the air to be injected in the next step. A slug of compressed air will be injected into the injection well at a rate sufficient to maintain or at least partially maintain the reservoir pressure equal to a value of about 50 percent of the average reservoir pressure observed at the time steam injection will have been terminated.

After injecting about 0.5 gas cap pore volumes of air, another slug of water equal to 0.2 gas cap pore volumes will be injected following the initial slug of air. A second slug of air about equal in volume to the first slug will be injected and this will be followed by a third slug of water about equal to 0.2 gas cap pore volume. The volume of the air slugs in reservoir barrels, i.e., at the pressure in the gas cap is based upon the average temperature and pressure in the gas cap section of the reservoir under reservoir conditions.

When the first slug of air contacts the heated portion of the gas cap, in which the temperature will be about 270°F or more, a large part of the air will be consumed through oxidation of the residual crude oil in the gas cap and along the gas-oil contact or interface. Ignition of the oil in the formation will occur in the approximate 550–650°F range and the burning temperature can

reach as high as about 1,250°F. The air flow rate will be high enough to eventually result in auto-ignition in the reservoir, which will generate additional heat. Calculations indicate the residual crude oil in the gas cap section of the reservoir (S_{or} = 10percent) (S_{or} means "residual oil saturation") will ignite spontaneously after about 65 hours of air injection when the air flow rate is 1,390 standard cubic feet per hour foot of productive interval.

The second slug of water injected after the air will scavenge heat from the area where combustion has occurred and will move this heat toward offset producer wells as steam or hot water. The water will "retard" the fingering and channeling of the next slug of air through the gas cap.

Approximately 100 million BTU per day can be generated in situ when one million cubic feet of air is burned per day.

During the above-described program combustion gases and condensate water will be produced from the offset producer wells. The oil rates from the producers will have accelerated from an initial rate of about 5 barrels of oil per day to a peak rate of about 50 barrels of oil per day per producing well at the time steam injection will have been terminated. During the time of alternate air-water injection the oil rate per producing well will average an estimated 25 to 30 barrels per day per well until there has been substantial depletion of the oil column. Without the alternate air-water injection program, the oil rates would decline from 50 BOPD per well at time steam injection is terminated to about 10 to 15 BOPD per well in 24 months. Therefore the alternate slug injection program can about double the oil recovery for the time period following the steaming of a pattern through a pressurizing effect in the gas cap and through the replacement of heat losses following steaming.

EXAMPLE

This estimated example illustrates how the invention can be used to recover liquid hydrocarbons from a heavy oil reservoir. Steaming has been effected for about two years in the field to which this example relates. Water and air will be injected at a later time.

Reservoir Conditions	
Area Underlain by Hydrocarbon-containing Interval	20 acres
Interval - Smackover Sandstone	
Depth to Top of Interval	3000 feet
Gross Thickness of Interval	70 feet
Net Thickness of Interval considered to be gas cap overlying oil column (layer)	50 feet
Net Thickness of oil column below gas cap	20 feet
Average Porosity of Sandstone	36 per cent
Residual Oil Saturation in gas cap at time process is applied	10 per cent of pore volume
Average Water Saturation in gas cap at time process is applied	20 per cent of pore volume
Range of Horizontal Permeability of Sandstone Interval	500 to 6000 millidarcies
Average Initial Reservoir Temperature	110 °F
Viscosity of crude oil at reservoir conditions, prior to steam injection	75 centipoise
Average Static Reservoir Pressure before steam injection (field under vacuum)	5 psia
Number of Producing Wells in area	8 wells
Number of Injection Wells	1 well
Oil Producing Rate per well per day before steaming	5 BOPD

When steaming has been judged sufficient, it will be discontinued. Water, which may be heated, will be injected according to the invention following which air will be injected to cause spontaneous ignition and combustion to produce the heat and pressure which will then drive the oil now of a lower viscosity, toward the production wells.

Referring now to the drawing there are shown an injection and two production wells. It will be understood that the injection well and each of the production wells are placed in the field and relative to each other according to the estimated configuration of the oil bearing formation and any gas cap extant. Any variation of one or more injection and one or more production wells can be employed. The depth to which the respect wells are sunk will also at least to an extent depend upon the nature of the formation and the extent to which it has been produced in any particular portion thereof.

Steam and when it is being injected water is passed through injection pipe **1** into injection well **2** and forced out into the formation through perforations in the casing **3.** Because of channeling most of the heat from the injected steam will be in the gas cap, largely. Thus, the steam increases the overall temperature of the formation in the vicinity of the injection well and in an area generally, as depicted, extending toward the production well or wells which can be at some real distance from the injection well. Production wells are indicated at **4** and **5.** An oil-water interface **6** ultimately established in the gas cap which is now heated and in which some condensation of steam has taken place. Water is injected, as described herein, following which air is injected through the injection well to cause the spontaneous ignition and the in situ combustion, as described herein. Oil flows by gravity and pressure thereupon, assisted by the combustion, its viscosity to have been lowered by the heat, toward the production wells **4** and **5,** the oil being produced from the wells and removed through production lines **7** and **8.**

One skilled in the art in possession of this disclosure having studied the same and knowing the test data upon any particular formation will know how to position, where to position and the spacing of the several

wells involved.

Reasonable variation and modification are possible within the scope of the foregoing disclosure, drawing and the appended claims to the invention and the essence of which is that there has been set forth a method for the secondary recovery of oil from an oil bearing formation preferably by treating the gas cap which may be extant thereon by first heating the same as by injection of a hot fluid, as described, followed by at least one slug of water which can be heated, and then followed by air all in quantities sufficient to in effect trap the air in the heated gas cap or other portion of the formation wherewith to cause auto-ignition and in situ combustion to create the heat and pressure desired and required.

I claim:

1. A method for the recovery of oil from an oil bearing formation having a gas cap associated therewith which method comprises heating the interstices of the gas cap and formation then injecting into the heated portion of the formation a quantity of water sufficient upon later injection of a combustion sustaining fluid substantially to retain the combustion sustaining fluid in said heated part of the formation as said combustion sustaining fluid displaces the water therefrom to the boundaries of the treated area, and then injecting a combustion sustaining fluid into the thus treated portion of the formation in quantities sufficient and for a time sufficient to cause auto-ignition and consequent in situ combustion to generate heat and pressure sufficient to cause oil contained in the formation to flow away from said injection well toward at least one production well.

2. A method of claim **1** wherein the heating of the intertices of the gas cap and formation is accomplished by injection of a heating fluid into the gas cap and formation.

3. A method of claim **2** wherein the heating fluid is chosen from among the group consisting of steam, combustion gases, carbon dioxide, and natural gas.

4. A method of claim **1** wherein the combustion sustaining fluid is chosen from among air and oxygen.

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