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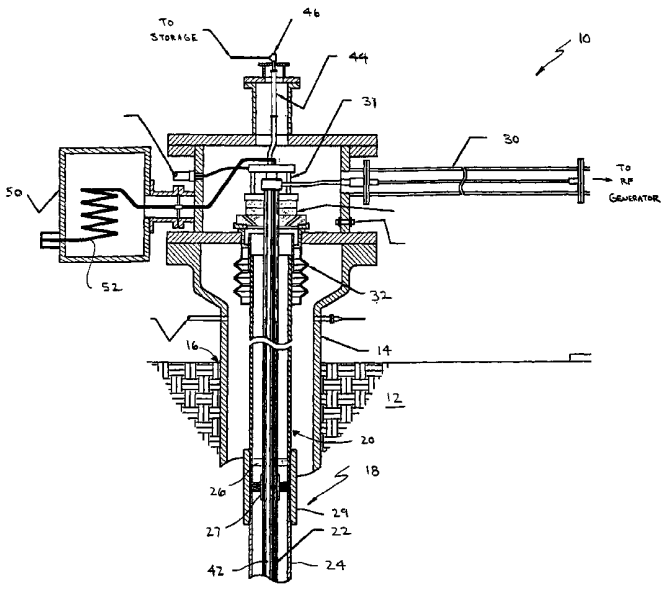
(54) Title: ELECTROMAGNETIC COAL SEAM GAS RECOVERY SYSTEM



(57) Abstract: A system for recovering gas trapped within the earth includes a casing (24) sized and configured to be positioned within a borehole in the earth, the casing (24) formed of a material that is transmissive to electromagnetic energy and gas within the earth; an antenna (40) sized and configured to be positioned within the casing (24). The antenna (40) has a distal end and a proximal end and including a radiating element at the distal end of the antenna (40) which, in operation, transmits electromagnetic energy toward a desired area of the earth, and an interior channel for allowing gas to be conveyed from the distal end to the proximal end of the antenna (40).

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

ELECTROMAGNETIC COAL SEAM GAS RECOVERY SYSTEM

BACKGROUND

The invention relates to the recovery of gas from subterranean formations in the earth.

Extensive and high volumes of hydrocarbon gases (e.g., methane) trapped within coal seams have been discovered in various parts of the United States. For example, large amounts of trapped methane gas have been discovered in eastern Wyoming (see, for example, "Powder River Basin Coalbed Methane Play Heats Up," E&P Perspectives, Vol. X, R57, October 22, 1998 (attached herewith). Naturally occurring degradation processes, such as the biodegradation of microorganisms in the coal is believed to cause the generation of the methane gas trapped within the coal seams.

Methods of economic and environmentally sound gas recovery are underway. A major problem encountered is the large amount of aquifers (water) that impedes the ability to recover the gas from bore holes drilled in to the coal seam. Specifically, the in-ground water serves as a barrier to the effective removal of the gas from the bore hole. The water must be removed by a pump or redirected to allow more efficient removal of the gas. Systems of co-generation of power for pumps are being considered for the prime supply of electrical energy for the pumps. That is, the electrical power for operating gas turbines used to drive the pumps could be generated using a portion of the gas removed from the borehole.

SUMMARY

In a general aspect of the invention, a system for recovering gas trapped within the earth, the system includes a casing sized and configured to be positioned within a borehole in the earth, the casing formed of a material that is transmissive to electromagnetic energy and gas within the earth, and an antenna sized and configured to be positioned within the casing. The antenna includes a radiating element at a distal end of the antenna which, in operation, transmits electromagnetic energy toward a desired area of the earth, and an interior channel for allowing gas to be conveyed from the distal end to a proximal end of the antenna.

In another aspect of the invention, a method system for recovering gas trapped within the earth includes the following steps. A casing is positioned within a borehole in the earth, the casing formed of a material that is transmissive to electromagnetic energy and gas within

the earth. An antenna is positioned within the casing, the antenna having a distal end and a proximal end. The antenna includes a radiating element at the distal end of the antenna which, in operation, transmits electromagnetic energy toward a desired area of the earth; and an interior channel for allowing gas to be conveyed from the distal end to the proximal end of the antenna. The method further includes applying electromagnetic energy to the antenna to radiate the earth surrounding the casing; drawing the gas within the earth into the interior channel of the antenna at the distal end of the antenna; and conveying the gas within the interior channel to the proximal end of the antenna.

Embodiments of these aspects of the invention may include one or more of the following features.

A product return pipe has a first end connected to the proximal end of the antenna and a removable cap attached to a second end of the product return pipe. A bellows is connected to the proximal end of the antenna. A thermocouple assembly is connected to the proximal end of the antenna.

The antenna is configured to operate in a frequency range between 300 KHz and 300 GHz. More particularly, the frequency range is between 1 MHz and 100 MHz (e.g., about 27 MHz). The antenna is configured to operate at a power level in a range between 3 Kwatts and 20 Kwatts (e.g., about 10 Kwatts).

Among other advantages, the system and method reduces the negative impact of water on the *in situ* recovery of coal gas, such as methane from underground beds or seams of coal; and (2) to provide additional or enhanced stimulation of gas production from the coal deposits.

The basic energy source proposed for reducing the water barrier effect and stimulating production *in-situ* is electromagnetics. Electromagnetic energy at frequencies as low as 60 Hz and extending into to microwave frequencies supplied by earth electrodes in the form of antennas and/or waveguides may be employed in the proposed processes. The basic idea is to introduce current into the subterranean formation to vaporize or boil the water in a specified region or of the coal seam. The currents are derived from the electromagnetic field energy absorbed by the coal material and water.

Specific in-ground applicator structures such as rod electrodes, antennas or waveguides and transmission lines provide the induced currents in the coal seam to vaporize a given amount of water. For example, antennas in a vertical or horizontal bore hole drilled

in a coal seam radiate electromagnetic energy away from the antenna into the coal creating a dry region around the bore hole/antenna structure. A pump can be used in conjunction with the antenna for water removal or the bore hole containing the antenna may be pressurized to keep the water away from the antenna/bore hole.

A special gas filtering system can be employed around the antenna (within or outside the bore hole) to permit gas recovery up the antenna bore hole without water. This special filter would block liquid water and allow only gas to pass through it. The dry region around the antenna borehole created by dielectric heating of the coal/water matrix is maintained by the power supplied by the antenna (e.g., 3 to 20 kilowatts on average).

This dry region, maintained by either resistive (low frequency) currents or dielectric (high frequency) currents in the coal seam, allows the gas to be transferred from regions outside the casing to within the antenna case, bore hole, or adjacent recovery wells equipment with special filters and flow lines for ease of gas recovery without water.

The dry sheath region or zone is maintained at approximately 100°C to ensure that there is no liquid water.

Thermal energy is not a requirement for the gas deposits in place. As a result of the dielectric sheath created by electromagnetic currents, the radiation fields of the antenna now extend further into the coal seam away from the antenna bore hole thereby creating an enhanced zone or region of heating and results in an enlargement of the dry zone and less impedance of gas flow to the recovery well by water.

Another benefit of electromagnetic heating is the enlargement of fracture zones in the coal seams by stream pressure and thermal gradients. The result is enhanced flow of methane gas to recovery wells.

Still another benefit of electromagnetic heating is the increased activity of microorganisms from the thermal energy deposit, especially at radio frequencies.

The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

Fig. 1 illustrates the upper portion of an RF gas recovery system in accordance with the invention.

Fig. 2 illustrates the lower portion of the RF gas recovery system of Fig. 1.

Fig. 3 illustrates an alternative embodiment of a lower portion of the RF gas recovery system of Fig. 1.

Fig. 4 illustrates another alternative embodiment of the lower portion of the RF gas recovery system of Fig. 1.

Fig. 5 illustrates still another alternative embodiment of the lower portion of the RF gas recovery system of Fig. 1.

Fig. 6 illustrates still another alternative embodiment of the lower portion of the RF gas recovery system of Fig. 1.

Fig. 7 illustrates still another alternative embodiment of the lower portion of the RF gas recovery system of Fig. 1.

Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

Referring to Figs. 1 and 2, the upper portion of an RF gas recovery system 10 is shown for radiating electromagnetic energy into a coal seam deposited within the ground 12 and extracting gas released by the heating generated by the electromagnetic energy. In particular, gas recovery system 10 includes an outer casing 14 disposed within a borehole 16 drilled deep within the ground. The outer casing 14 houses a coaxial RF applicator 18 that includes a coaxial transmission line 20 extending from the upper end of the antenna at the surface of the earth to a distal end of the antenna. The coaxial transmission line 20 includes a center conductor 22 positioned coaxially within an outer conductor 24. In this embodiment, center conductor 22 and outer conductor 24 have diameters of about 1 inch and 2.9 inches, respectively, and have lengths greater than 30 feet. In general, the length of the RF applicator 18 and the outer casing 14 can be between 8 and 200 feet. Insulative spacers (e.g., Teflon) 26 are spaced along the length of the center conductor 22 to maintain its coaxial position relative to the outer conductor 24. Furthermore, due to the relative long length of RF applicator 18, support collars 27 are spaced periodically along the length of center conductor 22. Similarly, support collars 29 are spaced periodically along the length of outer 24. The upper end of the coaxial transmission line 20 is connected to an RF generator (not shown) via an RF coax line 30. The upper ends of center conductor 22 and outer conductor

24 of coaxial transmission line 20 include expansion joints in the form of bellows 31,32, respectively.

As shown in Fig. 2, in this embodiment, the distal end of the RF applicator includes a dipole antenna 40 extending between 5-6 feet from the end of coaxial transmission line 20. In operation, dipole antenna 40 receives RF energy from the RF generator via coaxial transmission line 20 to and radiates the coal seam deposit in the surrounding earth. As will be described in greater detail below, the radiated RF energy heats the coal and, in particular, vaporizes or boils the water in a specified region or of the coal seam. By removing the water from the coal seam, methane and other gases trapped within the coal seam are released and more easily removed.

Center conductor 22 of transmission line 20 is dual-purposed. The center conductor not only serves as part of the structure for heating the water in the coal seam, it also provides an inner passage 42 or conveying the gas to the surface of the earth for processing. To remove the gas, a product return pipe 44 having a removable plug 46 extends from the end of center conductor at bellows 32.

RF gas recovery system also includes a thermocouple assembly 50 having a thermocouple coil 52 connected to bellows 32. Thermocouple coils serves as a filter to "choke" or prevent the flow of low frequency currents to flow. **(Ray?)** Outer casing 14 also includes input pipes 56 through which nitrogen gas is introduced within the casing. The nitrogen gas is much less flammable than oxygen and, therefore, provides a much safer safe environment for introducing high current levels from RF applicator 18.

The operation of this particular embodiment will now be described. In general, ... RF energy is transmitted from the RF generator to dipole antenna 40 via coaxial transmission line 20. Dipole antenna 40 induces currents within the coal seam

What is claimed is:

1. A system for recovering gas trapped within the earth, the system comprising:

a casing sized and configured to be positioned within a borehole in the earth, the casing formed of a material that is transmissive to electromagnetic energy and gas within the earth;

an antenna sized and configured to be positioned within the casing, the antenna having a distal end and a proximal end and including:

a radiating element at the distal end of the antenna which, in operation, transmits electromagnetic energy toward a desired area of the earth; and

an interior channel for allowing gas to be conveyed from the distal end to the proximal end of the antenna.

2. The system of claim 1, further comprising a product return pipe having a first end connected to the proximal end of the antenna and a removable cap attached to a second end of the product return pipe.

3. The system of claim 1, further comprising a bellows connected to the proximal end of the antenna.

4. The system of claim 1 further comprising a thermocouple assembly connected to the proximal end of the antenna.

5. The system of claim 1 wherein the antenna is configured to operate in a frequency range between 300 KHz and 300 GHz.

6. The system of claim 5 wherein the antenna is configured to operate in a frequency range between 1 MHz and 100 MHz.

7. The system of claim 6 wherein the antenna is configured to operate at a frequency of about 27 MHz.

8. The system of claim 6 wherein the antenna is configured to operate at a power level in a range between 3 Kwatts and 20 Kwatts.

9. The system of claim 8 wherein the antenna is configured to operate at a power level of about 10 Kwatts.

10. A method for recovering gas trapped within the earth, the method comprising:

positioning a casing within a borehole in the earth, the casing formed of a material that is transmissive to electromagnetic energy and gas within the earth;

positioning an antenna within the casing, the antenna having a distal end and a proximal end, the antenna including:

a radiating element at the distal end of the antenna which, in operation, transmits electromagnetic energy toward a desired area of the earth; and

an interior channel for allowing gas to be conveyed from the distal end to the proximal end of the antenna;

applying electromagnetic energy to the antenna to radiate the earth surrounding the casing;

drawing the gas within the earth into the interior channel of the antenna at the distal end of the antenna; and

conveying the gas within the interior channel to the proximal end of the antenna.

11. The method of claim 10 further comprising attaching a first end of a product return pipe to the proximal end of the antenna and attaching a removable cap to a second end of the product return pipe.

12. The method of claim 10 further comprising attaching a bellows to the proximal end of the antenna.

13. The method of claim 10 further comprising attaching a thermocouple assembly connected to the proximal end of the antenna.

14. The method of claim 10 wherein the electromagnetic energy is in a frequency range between 300 KHz and 300 GHz.

15. The method of claim 14 wherein the electromagnetic energy is in a frequency range between 1 MHz and 100 MHz.

16. The method of claim 15 wherein the electromagnetic energy has a frequency of about 27 MHz.

17. The method of claim 15 wherein the electromagnetic energy is at a power level in a range between 3 Kwatts and 20 Kwatts.

18. The method of claim 17 wherein the electromagnetic energy is at a power level of about 10 Kwatts.

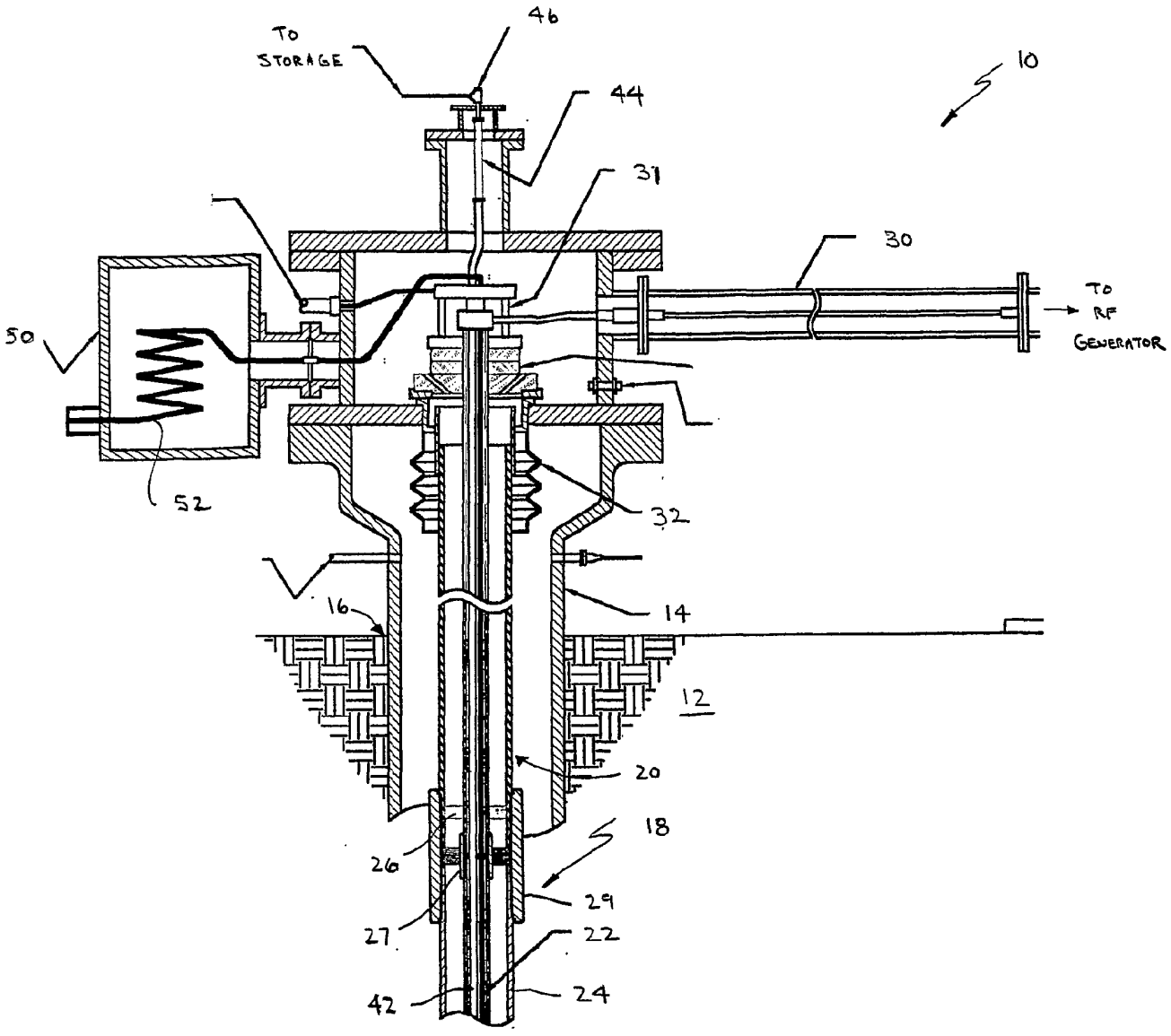
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Fig. 1

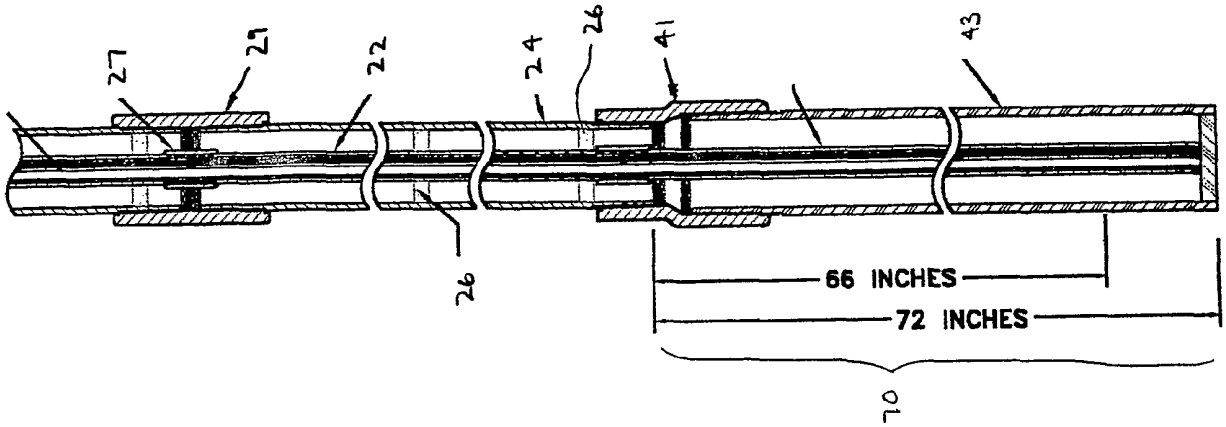
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Fig. 3

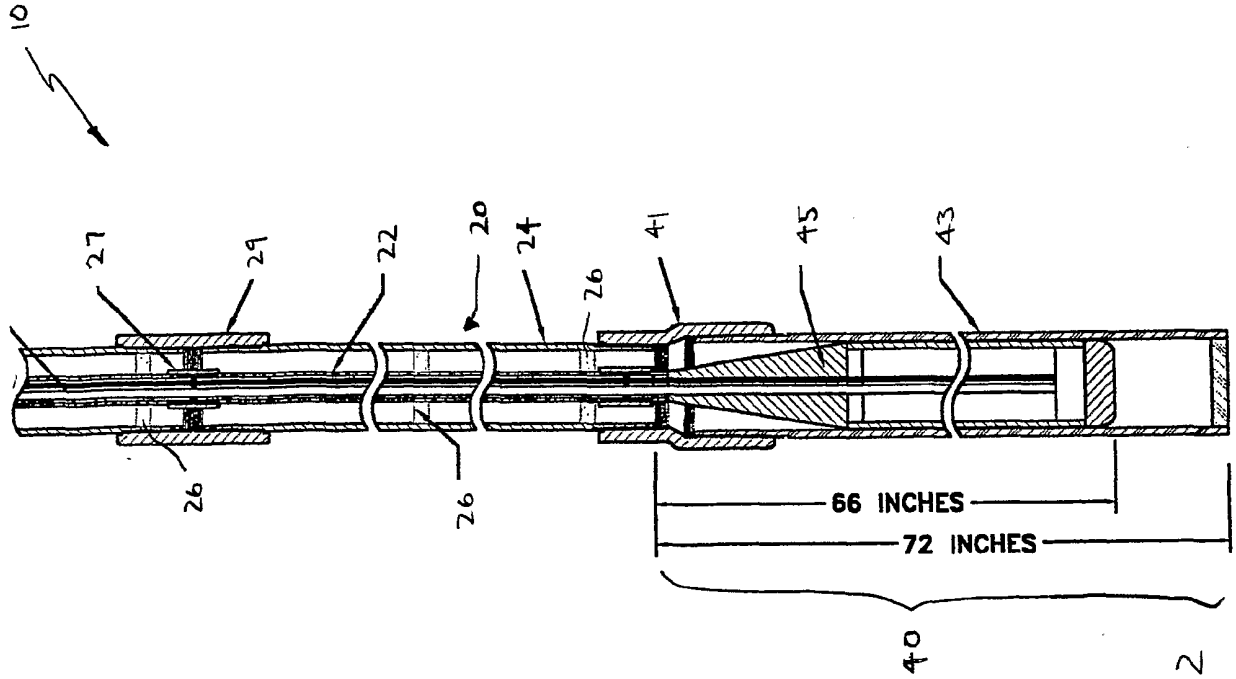
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Fig. 2

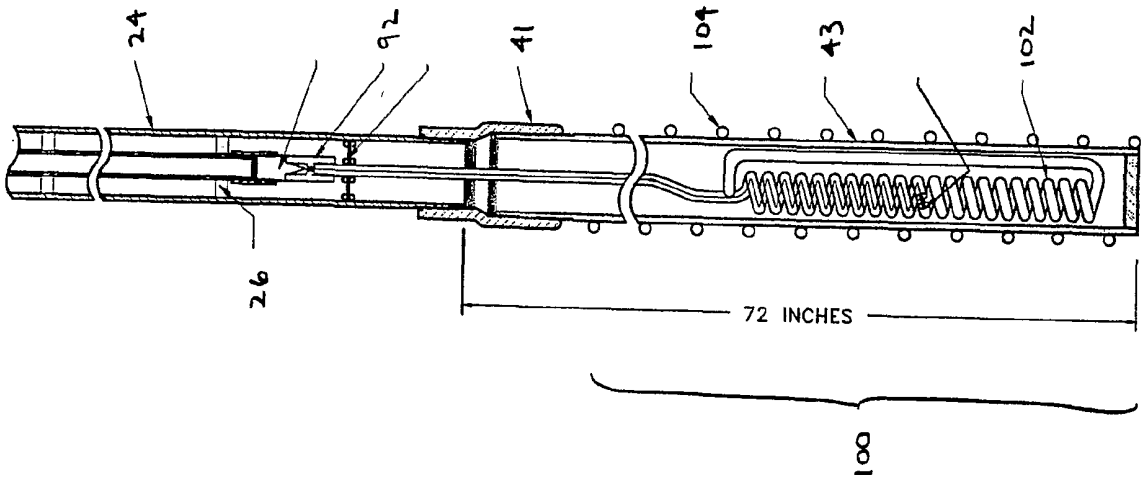
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Fig. 5

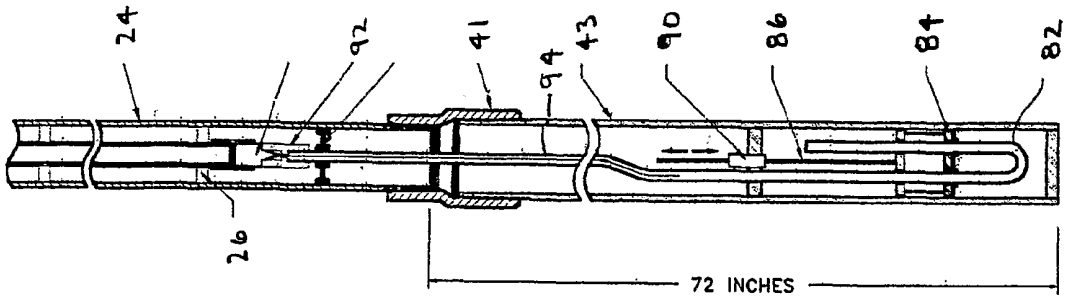
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Fig. 4

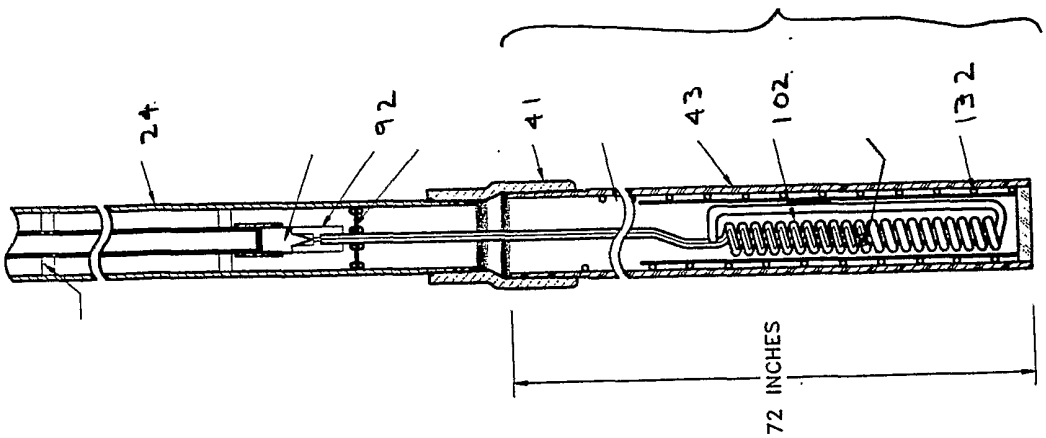

Fig. 7

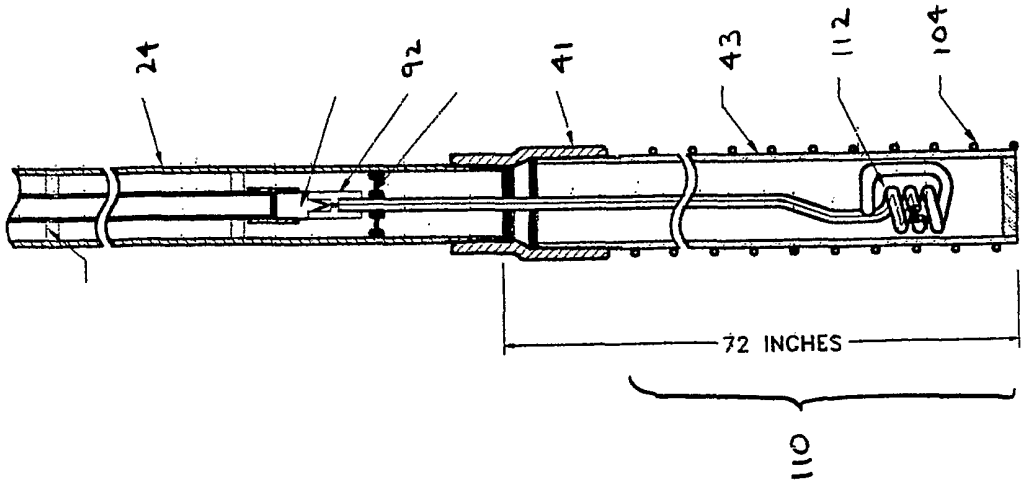

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/49083

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :E21B 43/00
US CL : 166/248, 66.5; 340/854.6
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 166/248, 66.5

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, P	US 6,189,611 B1 (KASEVICH) 20 FEBRUARY 2001, see entire document.	1,2,5-11, 14-18
A	US 5,055,180 A (KLAILA) 08 OCTOBER 1991, see entire document.	1, 10
A	US 4,817,711 A (JEAMBEY) 04 APRIL 1989, see entire document	1, 10
A	US 4,912,971 A (JEAMBEY) 03 APRIL 1990, see entire document	1, 10

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
01 MAY 2002	28 MAY 2002
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer ROGER J. SCHOEPPEL Telephone No. (703) 308 2147

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