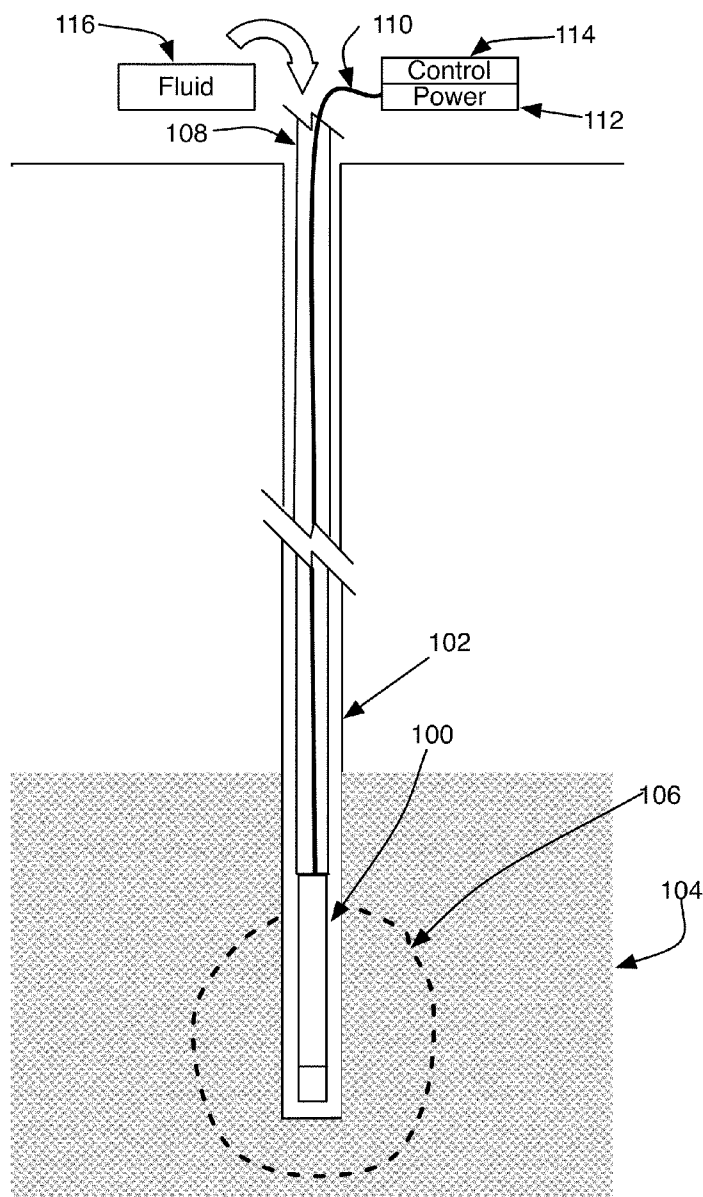




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(19) **United States**(12) **Patent Application Publication**
Dennis(10) **Pub. No.: US 2012/0012319 A1**(43) **Pub. Date: Jan. 19, 2012**(54) **ENHANCED HYDROCARBON RECOVERY
USING MICROWAVE HEATING****Publication Classification**(51) **Int. Cl.***E21B 43/24* (2006.01)*E21B 36/00* (2006.01)(52) **U.S. Cl.** **166/302; 166/66.5**(57) **ABSTRACT**

A downhole tool utilizing microwave energy for stimulating production of hydrocarbons from a drilled well. A microwave generator is disposed within the body of the tool and supplied with power from the surface. Microwaves generated by the tool are applied to a refractory dielectric material disposed at a lower end of the tool or to dielectric material in fluids circulated into the wellbore, or directly to the formation.

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TX (US)(21) **Appl. No.:** **12/838,006**(22) **Filed:** **Jul. 16, 2010**

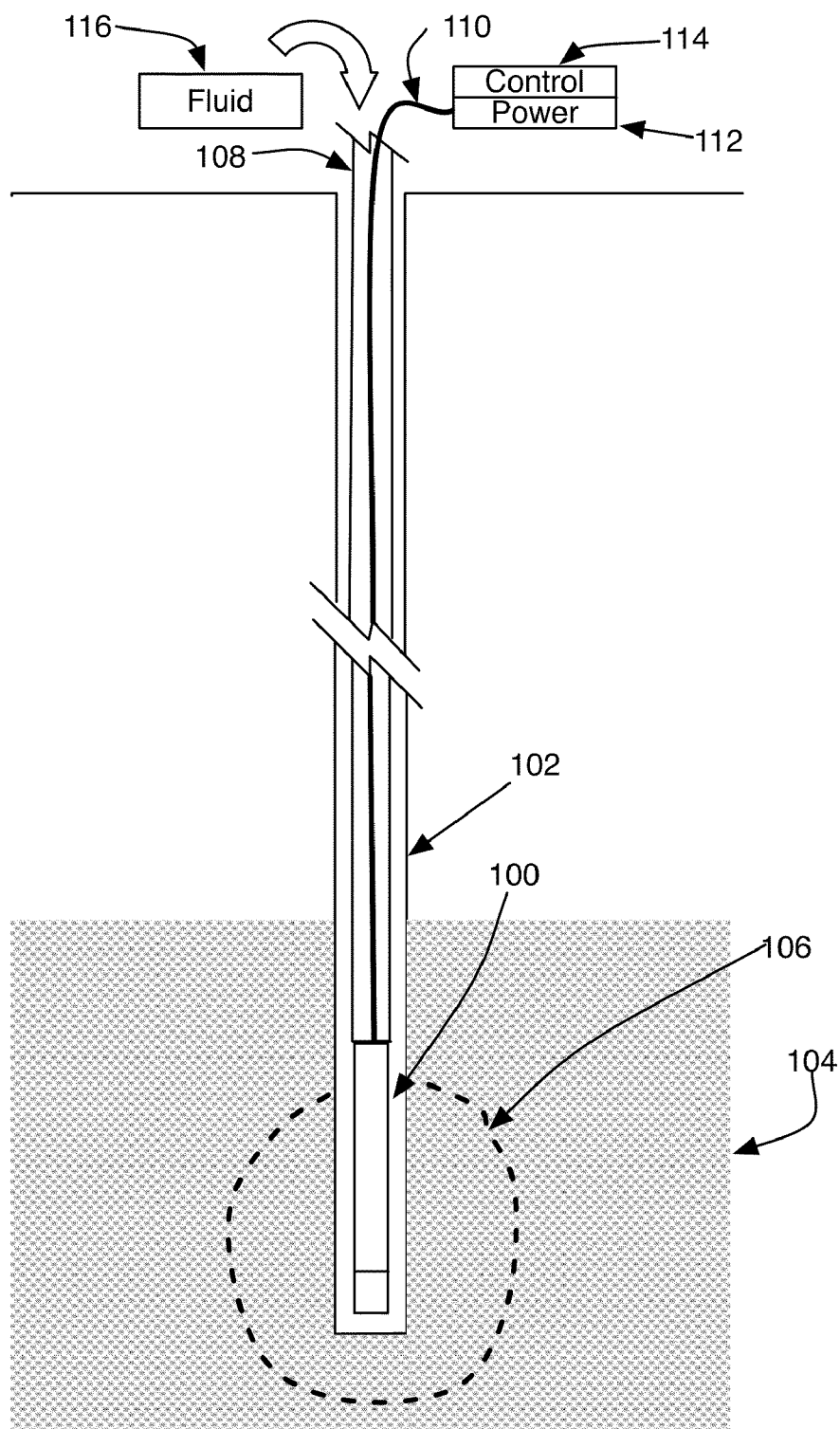


FIG. 1

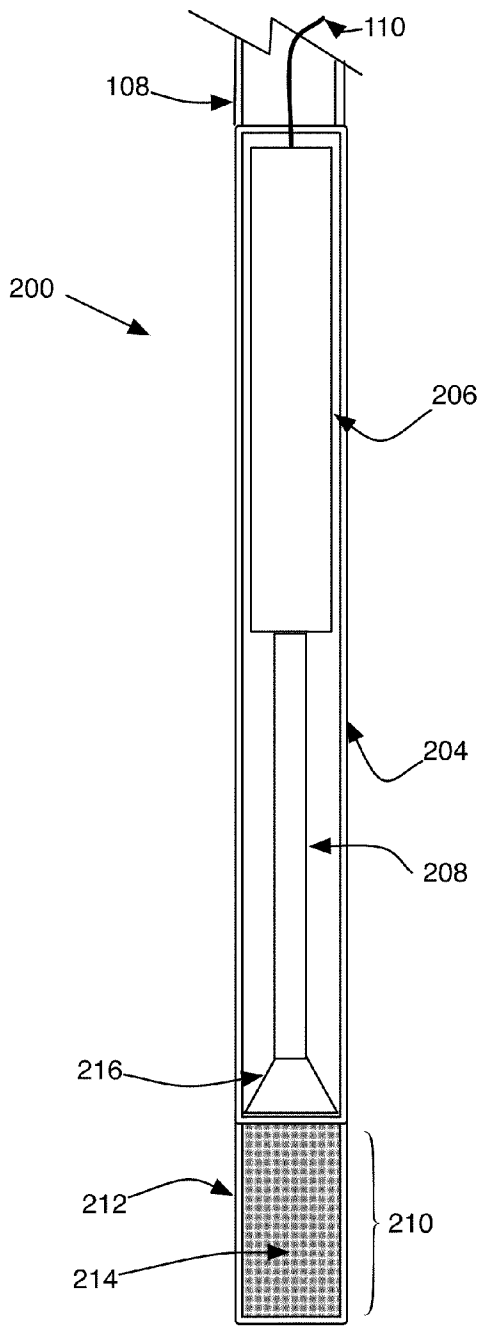


FIG. 2

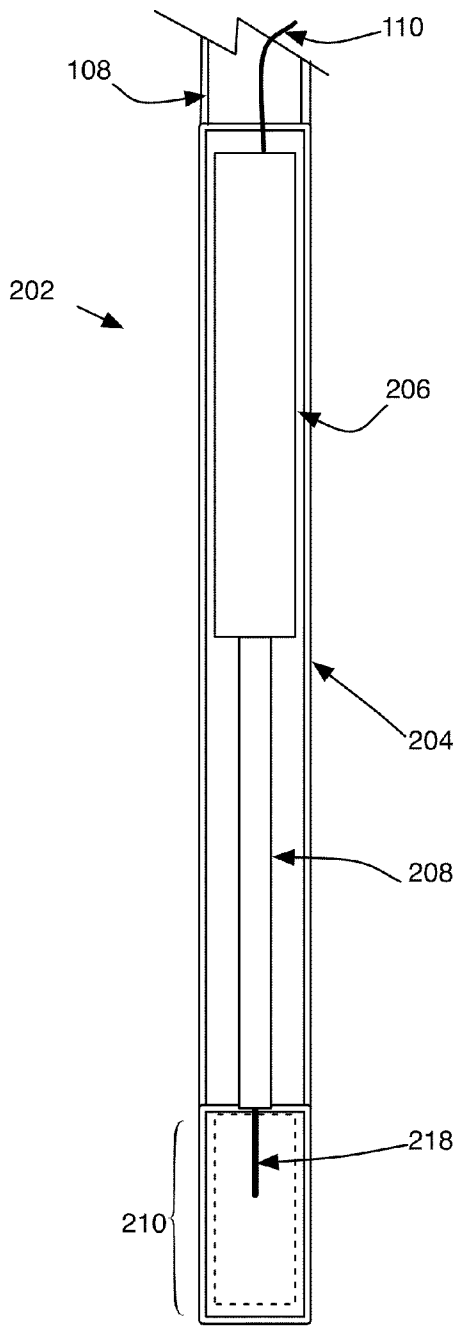


FIG. 3

ENHANCED HYDROCARBON RECOVERY USING MICROWAVE HEATING

BACKGROUND

[0001] There are a number of techniques used to stimulate or enhance production of hydrocarbons from wells by increasing the permeability of the formation outside the wellbore. The most well-known and widely used approach is hydraulic fracturing of the formation to increase permeability. In-situ heating of hydrocarbon bearing formations has also been used to address production problems relating to fluids in the reservoir rock and the production equipment, such as deposition of wax and asphaltene materials, creation of water and oil emulsion, fluid invasion resulting in clay swelling and fines migration. However, thermal stimulation of a formation can also be used to fracture the formation through thermal expansion of materials comprising the formation, as well as to improve fluid flow characteristics of near-wellbore porous regions by reducing the viscosity of the oil, preventing or removing waxes or asphaltenes build-up in the wellbore and near-wellbore region, preventing formation of hydrates and dehydrating clay.

SUMMARY

[0002] The invention pertains, generally, to stimulating production of hydrocarbons from a well by lowering a downhole tool into a wellbore to generate microwave radiation for heating.

[0003] A first, exemplary embodiment of a downhole tool comprises a microwave generator positioned for generating microwave radiation and a transmission line for carrying microwave electromagnetic energy from the generator towards a microwave absorbable material disposed within a head portion of the tool. After the tool is lowered into the borehole using jointed pipe or coiled tubing, electric energy is supplied to the microwave generator, causing microwave radiation to be generated. This radiation is directed to, and absorbed by, the microwave absorbable material causing it to heat. The thermal energy is transferred to fluids in the borehole through thermal conduction, and then to the adjoining formation.

[0004] A second, exemplary embodiment of such a downhole tool comprises a microwave generator and a transmission line that carries the microwave electromagnetic energy from the generator toward a head, at least a portion of which is made from microwave transparent material. The microwave radiation travels through the head and then is radiated from an antenna so that microwave absorbable materials within fluids within the wellbore and/or surrounding hydrocarbon-bearing formation absorb the microwave radiation. The microwave radiation absorbed by the well fluid and/or the microwave absorbable material within the rock formation results in heating of the rock formation. The head may optionally include a reflecting element for directing or focusing the radiation, or for scattering the radiation.

[0005] According a method for using the tool, the tool is lowered into the borehole to the desired position, and the microwave generator is turned on to generate microwave electromagnetic energy that is transmitted toward the head of the tool. Optionally, drilling fluid to which microwave absorbable material has been added is circulated into the wellbore so that the microwave radiation heats the microwave absorbable material. Depending on the formation and how the

downhole is used, the heating stimulates flow of hydrocarbons by either reducing its viscosity or causing thermal expansion that leads to fracturing of the formation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1 is a schematic illustration of a wellbore into which is lowered a downhole tool for generating heat within the wellbore and adjoining formation.

[0007] FIG. 2 is a schematic illustration of a first embodiment of the downhole tool shown in FIG. 1.

[0008] FIG. 3 is a schematic illustration of a second embodiment of the downhole tool shown in FIG. 1.

DETAILED DESCRIPTION

[0009] In the following description, like features or elements are marked throughout the specification and drawings with the same reference numerals, respectively.

[0010] Referring to FIG. 1, downhole tool **100** is lowered into wellbore **102** and positioned next to a region of interest **106** in a hydrocarbon bearing formation **104**. The tool **100** is lowered into and supported within the wellbore at a desired location on the end of, in this example, continuous or coiled tubing **108**. Because the wellbore has already been drilled and is likely filled with fluid, lowering the tool using coiled tubing will allow the tool to be pushed into the wellbore until such time as the weight of the tool and the tubing overcomes the hydrostatic pressure within the well. However, a string of jointed pipe or, if the conditions permit, a wireline could also be used to lower the tool within the wellbore. The tool is supplied with electricity by an instrumentation cable **110** running through the tubing connected to a power source **112** located on the surface.

[0011] A controller **114** controls operation of the tool. One example of a controller comprises a circuit that turns power to the tool on or off, or that changes the voltage and/or current of the electricity being supplied to the tool. Another example is a circuit that generates and transmits to the downhole tool control signals understood by a controller within the downhole tool, which in turn causes the tool to operate or to stop operation, or to change an operational characteristic. The signals can be transmitted, for example, over cable **110**, another wire that runs to the downhole tool from the surface, the continuous tubing or jointed pipe that lowers the tool into the hole, or using RF communication methods. The controller may also include logic implemented using just hardware or a combination of hardware and software (for example a specially programmed processor) for performing one or more predetermined or programmed control processes.

[0012] Drilling fluid from a source **116** on the surface supplies fluid containing microwave absorbable compounds. The fluid can be drilling fluid to which such compounds have been added. The fluid can be pumped down continuous tubing or jointed pipe inserted into the bore hole prior to the tool **100** being lowered into the bore hole, or while the tool is in the bore hole by, for example, pumping fluid through the tubing or pipe to which the tool is connected and having the fluid exit openings into the bore hole above or in the tool.

[0013] FIGS. 2 and 3 illustrate, respectively, alternative embodiments **200** and **202** of downhole tool **100** from FIG. 1. Each of the embodiments **200** and **202** includes a body **204** that forms an enclosure. The body is comprised, for example, of a hollow, sleeve-shaped element made of steel, stainless steel, or other material or combination of materials capable of

withstanding the relatively high temperature and pressure and corrosive environment of the wellbore. The body can be comprised, for example, of one or more lengths of metal tubing having a diameter smaller than the diameter of the borehole **102**.

[0014] Enclosed within the body is at least one microwave generator **206** and a waveguide **208** for transmitting microwaves from the generator to head **210** (for the embodiment of FIG. 2) or head **212** (for the embodiment of FIG. 3). The body protects the microwave generator. The head attaches to a distal end of the body. A coaxial cable could be substituted for the waveguide. The microwave generator is operable to generate microwave energy while the tool is disposed within the borehole using power supplied from the surface via, for example, line **110**. The microwave energy that is generated is coupled with a microwave absorbing material disposed within a head portion **210** of FIG. 2, of the tool or, in the example of FIG. 3, within fluid circulated into the borehole or in a portion of the rock formation adjacent to the downhole tool. The microwave generator is thermally isolated from the head by distance and/or by use of a thermal insulating material (not shown in the drawings). Alternately, or additionally, the body may incorporate a cooling system for the generator. An example of a cooling system includes the use of fluid, such as drilling fluid, supplied to the tool through tubing connected to the proximal end of the tool. The fluid could, for example, enter the top or proximal end of the tool, and flow past generator **206** and then out openings in the tool nearer the distal end of the body **204** of the tool or in the head of the tool. The generator and related equipment and wiring would be enclosed within a suitable protective housing with heat exchanging surfaces disposed on it.

[0015] The microwave generator may take the form of, for example, a magnetron, a klystron or a travelling tube. It could, alternatively, utilize solid state devices rather than vacuum tubes. The generator **206** that is schematically illustrated includes additional elements such as a power supply for rectifying and stepping up voltage, an adaptor for coupling the generator to the waveguide, an isolator for preventing reflected microwave energy from entering the generator, and a controller and other instrumentation for controlling and/or monitoring the operation of the generator. The body can also house other auxiliary equipment, such as instrumentation for reporting the temperature of various parts of the generator and the head. The generator may be tuned to operate at standard frequencies set aside for industrial application or scientific applications, such as 915 MHz, 2.45 GHz, 5.8 GHz and 22.125 GHz. However, it could be tuned to a frequency within the microwave range of 300 MHz to 300 GHz. The frequency being chosen depending at least in part on the material that is intended to be heated by the microwave energy from the generator.

[0016] In the embodiment of FIG. 2, microwave absorbable material is placed in head **210** and is heated by microwave energy generated by the microwave generator. In the embodiment of FIG. 3, microwave energy generated by the generator is radiated into either drilling fluid containing microwave absorbable material and/or into the rock formation adjacent to the tool through a radiating element (i.e. an antenna) disposed within a microwave transparent head **212** or window within head **212**.

[0017] Referring only to FIG. 2, the head **210** is comprised of a support structure, for example enclosure **212**, for supporting a plurality of microwave absorbing elements **214**

comprised of microwave absorbing material disposed within the head. The support structure can include additional elements (not shown) for positioning and retaining the element within the head. The microwave absorbing material absorbs microwave energy at the frequency or range of frequencies at which the generator operates, thereby causing the material to heat. In this example, the microwave absorbing material is a refractory, dielectric material. The material preferably also has a relatively high loss factor. Examples of a refractory dielectric material particularly suitable for the downhole tool include silicon nitride (Si₃N₄), graphite, and silicon carbide. A microwave absorbing element can be made or fabricated by sintering a microwave absorbable compound into the shape of, for example, a rod or pellet.

[0018] In the example of FIG. 2, the support structure is made of a refractory material, with a melting point above the highest temperature that the microwave absorbing material is intended to operate. The supporting structure is machined or fabricated from a material that is, in one embodiment of this example, transparent to the microwave radiation. Portions of the structure exposed to the environment of the wellbore are preferably made from a corrosion and abrasion resistant material. Examples of corrosion resistant, microwave-transparent materials suitable for this application include sialon, an alloy containing silicon nitride and aluminum. The structure transfers heat from the microwave absorbing material **214** to the environment surrounding the tool, in particular fluid within the borehole, through conduction. The fluid then transfers the heat by convection to the surrounding geological formation. Although shown as enclosing microwave absorbing material, an alternative embodiment of the head **210** could include openings for permitting fluid at the bottom of the wellbore to flow through the head and thereby directly contact the microwave absorbing material.

[0019] Microwave energy transmitted from the waveguide **208** is coupled to the microwave absorbable elements **214** by an applicator, which is generally indicated by reference number **216**. Although the illustrated applicator comprises a feed horn, it is intended only to be representative. Other types of applicators could be utilized, including resonant, travelling-wave and near-field applicators. Near-field applicators include open-ended waveguides, slotted waveguides and antennas. An applicator may extend into the head, depending on the type of applicator utilized. In the case of a resonant applicator, a resonant cavity can be, for example, formed within the head **210** and coupled with the waveguide. The cavity could resonate in a single mode or a multi-mode.

[0020] Referring to FIG. 3, the head **212** has at least a window (not illustrated) formed therein of a material that is transparent to microwave radiation. The entire head can be made of such material, or combination of materials. Portions of the structure exposed to the environment of the wellbore are preferably made from a corrosion and abrasion resistant material. Examples of materials that are microwave transparent and resistant to corrosion and abrasion include sialon. In this example, the waveguide terminates in a near-field applicator, represented by antenna **218**, for radiating electromagnetic energy transmitted from the microwave generator into the wellbore and/or surrounding formation. The illustrated antenna is a dipole. However, other forms of antennae can be used. Furthermore the radiation can be redirected or focused to a particular area within formation predetermined patterns using one or more reflecting surfaces, and can also be scattered using stationary or dynamic antennae.

[0021] The foregoing description is of an exemplary and preferred embodiments employing at least in part certain teachings of the invention. The invention, as defined by the appended claims, is not limited to the described embodiments. Alterations and modifications to the disclosed embodiments may be made without departing from the invention. The meaning of the terms used in this specification are, unless expressly stated otherwise, intended to have ordinary and customary meaning and are not intended to be limited to the details of the illustrated structures or the disclosed embodiments.

What is claimed is:

1. A downhole tool, comprising:
 - an elongated body having dimensions for fitting into a wellbore suitable for production of hydrocarbons, the enclosure having a proximal end adapted for connection to a means for lowering the enclosure into the wellbore;
 - a microwave generator generating electromagnetic energy at predetermined microwave wavelengths, the generator disposed within the body and operable to receive power through a cable extending through the proximal end of the enclosure;
 - a transmission line for transmitting the electromagnetic energy from the microwave generator to a head of an applicator located near a distal end of the body, remote from the microwave generator; and
 - a head attached to the body and forming a distal end of the tool.
2. The downhole tool of claim 1, wherein at least a portion of at least one wall of the head unit being comprised of a microwave transparent, refractory material, and wherein the applicator is located at least partially within the head and radiates microwave energy through the microwave transparent refractory material.
3. The downhole tool of claim 2, wherein the at least one exterior wall of the head is comprised of an abrasion-resistant, refractory material.
4. The downhole tool of claim 1, further comprising at least one microwave absorbable element disposed within the head for heating the head in response to absorbing at least a portion of said microwave energy from the applicator.
5. The downhole tool of claim 3, wherein the at least one microwave absorbing element material is comprised of one of silicon carbide, graphite, and silicon-nitride.
6. The downhole tool of claim 1, wherein the transmission line comprises a waveguide.
7. The downhole tool of claim 1, further comprising thermal insulation disposed within the body between the microwave generator and the head.
8. The downhole tool of claim 1, further including means for cooling the microwave generator.
9. The downhole tool of claim 1, wherein the microwave generator and the head are separated by a predetermined distance sufficient to substantially reduce transfer of heat from the head to the microwave generator.
10. An apparatus for stimulating production in a well drilled through a hydrocarbon-bearing formation, comprising:
 - a downhole tool disposed within a wellbore adjacent to a formation to be heated by the downhole tool comprising, an elongated body having dimensions for fitting into a wellbore suitable for production of hydrocarbons, the

enclosure having a proximal end adapted for connection to a means for lowering the enclosure into the wellbore;

- a microwave generator generating electromagnetic energy at predetermined microwave wavelengths, the generator disposed within the body and operable to receive power through a cable extending through the proximal end of the enclosure;
 - a transmission line for transmitting the electromagnetic energy from the microwave generator to a head of an applicator located near a distal end of the body, remote from the microwave generator;
 - a head attached to the body and forming a distal end of the tool;
- means for lowering the downhole tool into the wellbore extending from the earth's surface above the wellbore, into the wellbore and connect to the downhole tool;
- a power source located on the earth's surface; and
- a cable for coupling the power from the power source to the microwave generator, the cable running down the wellbore.
11. The apparatus of claim 10, wherein at least a portion of at least one wall of the head unit is comprised of a microwave transparent, refractory material.
 12. The apparatus of claim 10, wherein the at least one exterior wall of the head is comprised of an abrasion-resistant, refractory material.
 13. The apparatus of claim 10, further comprising at least one microwave absorbable element disposed within the head for heating the head in response to absorbing at least a portion of said microwave energy from the applicator.
 14. The apparatus of claim 10, wherein the at least one microwave absorbing element material is comprised of one of silicon carbide, graphite, and silicon-nitride.
 15. The apparatus of claim 10, wherein the transmission line comprises a waveguide.
 16. The apparatus of claim 10, further comprising thermal insulation disposed within the body between the microwave generator and the head.
 17. The apparatus of claim 10, further comprising fluid containing microwave absorbable material within the borehole adjacent to the head.
 18. A method for stimulating hydrocarbon recovery from a wellbore comprising:
 - lowering a downhole tool into a wellbore adjacent to a hydrocarbon bearing formation of interest, the downhole comprising:
 - an elongated body dimensioned and shaped for fitting into a wellbore drilled for production of hydrocarbons;
 - a microwave generator disposed within the body, near a proximal end of the body, for generating electromagnetic energy at predetermined microwave wavelengths, the microwave generator adapted for receiving power through a cable extending from the surface;
 - a transmission line for transmitting the electromagnetic energy from the microwave generator to an applicator located near a distal end of the body, remote from the generator; and
 - a head attached to a distal end of the body; and
 - applying power to the microwave generator with a cable extending from a power supply on the surface to the tool within the wellbore.

19. The method of claim **18**, wherein the tool is lowered on continuous tubing.

20. The method of claim **18**, further comprising circulating within the wellbore near the downhole tool a fluid containing dielectric material for heating by microwaves generated by the tool.

21. The method of claim **20**, wherein at least a portion of at least one wall of the head unit being comprised of a microwave transparent, refractory material, and wherein the applicator is located at least partially within the head and radiates

microwave energy through the microwave transparent refractory material, to the microwave absorbable material.

22. The method of claim **18**, wherein the tool further comprises at least one microwave absorbable element disposed within the head for heating the head in response to absorbing at least a portion of said microwave energy from the applicator.

23. The method of claim **22**, wherein the at least one microwave absorbing element material is comprised of one of silicon carbide, graphite, and silicon-nitride.

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