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(54) **DOWNHOLE HEATER ASSEMBLY AND POWER LINE COMMUNICATIONS SYSTEM**

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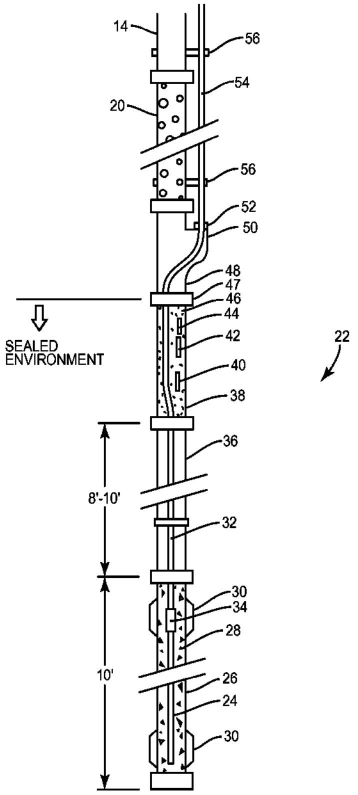
USPC **166/250.01**; 166/60; 166/53

(57) **ABSTRACT**

A hydrocarbon heating system comprises a surface control panel and a subsurface heating system, connected by an external power cable which also serves as the data communication link between the two parts. The subsurface heating system includes a heating element and two separate, thermally isolated temperature sensors. One thermal sensor, mounted near the heating element, monitors the temperature of the heating element. Another thermal sensor monitors the ambient temperature of fluid in the borehole. The temperature of the heating element may be varied to maintain an optimal well temperature for the production of hydrocarbons. Downhole electronics convert the thermal sensor outputs to digital data, and modulate the digital data onto a power cable that carries power from the surface to the heating element. A control system at the surface controls the heating element via nested control loops monitoring the temperatures of the borehole fluid and the heating element.



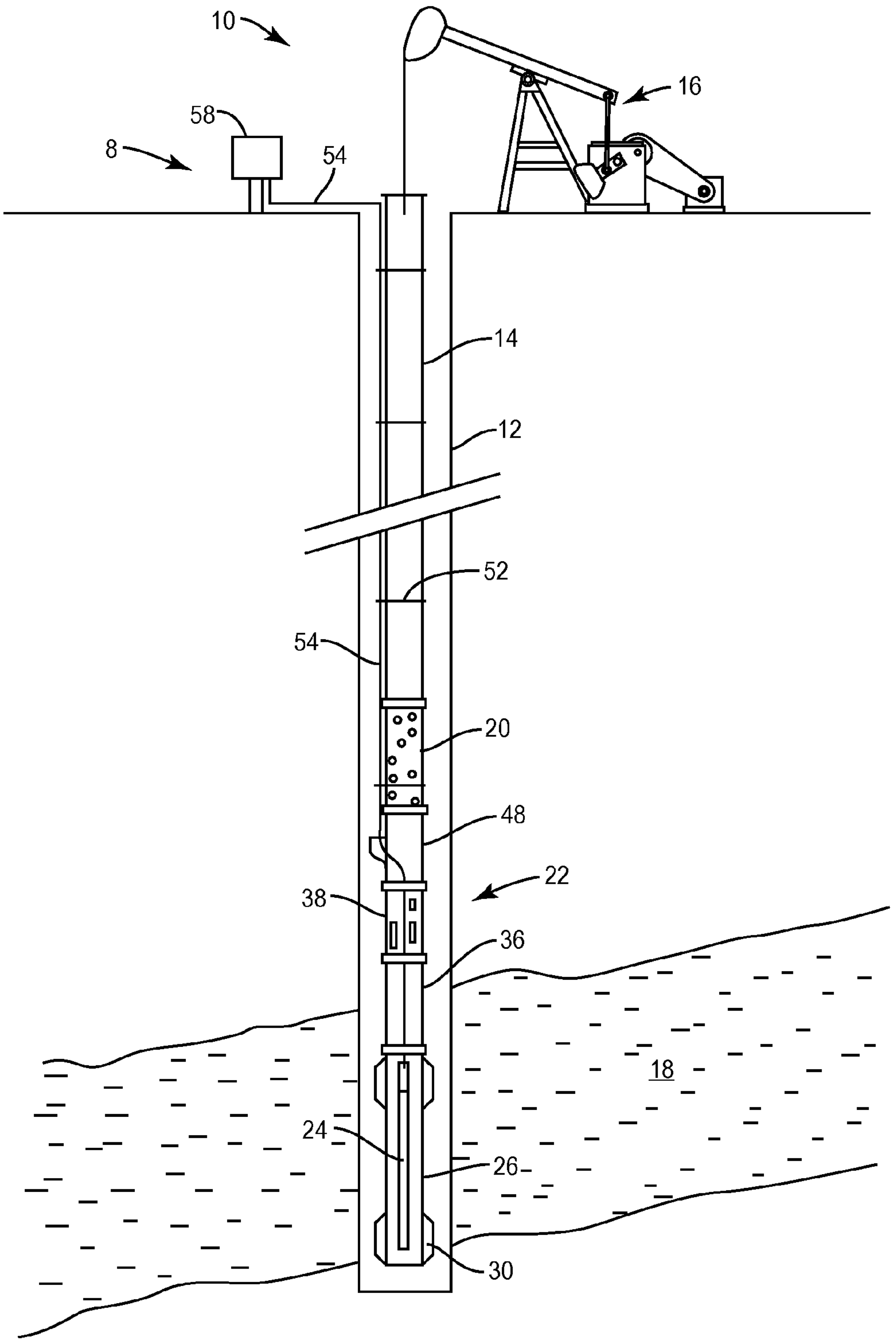


FIG. 1

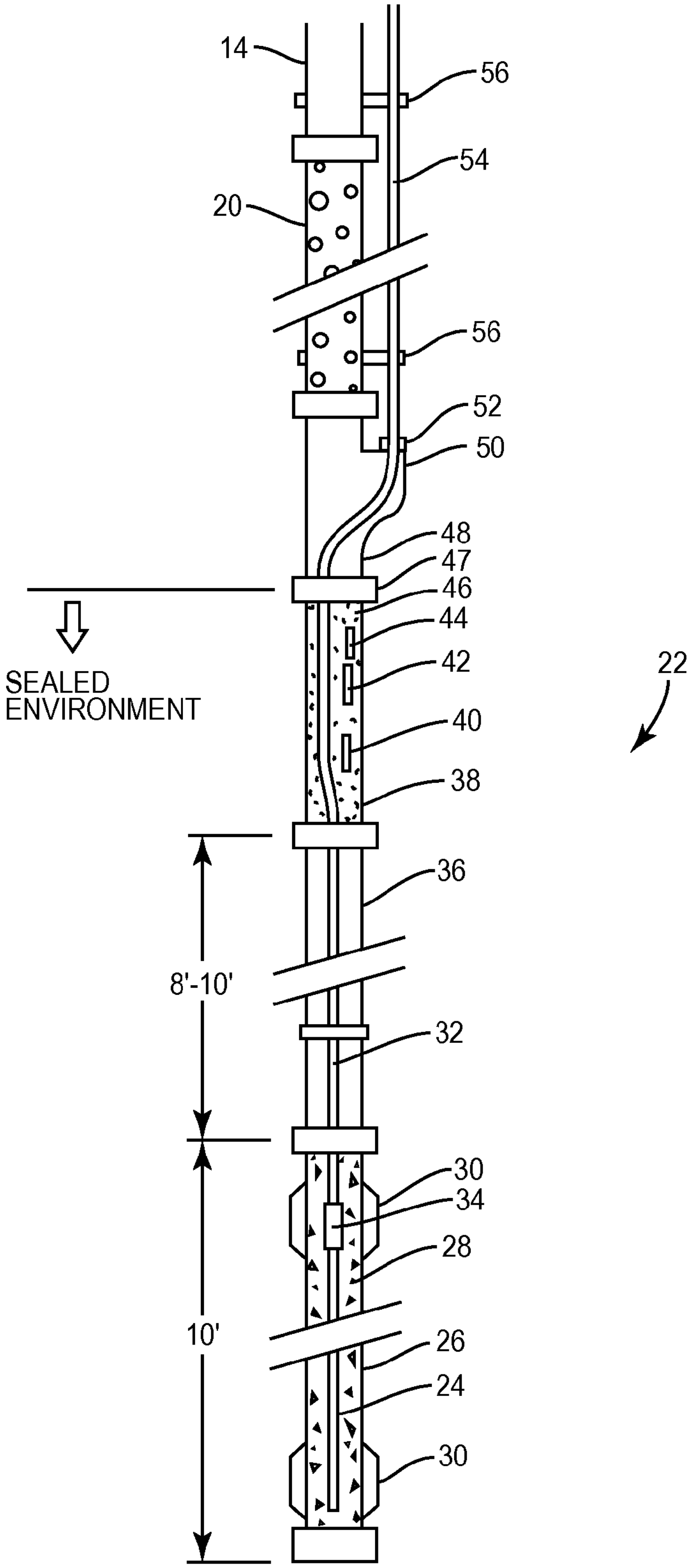

14
56
54
20
56
52
50
48
47
46
44
42
40
38
SEALED ENVIRONMENT
22
36
8'-10'
32
30
34
28
10'
26
24
30

FIG. 2

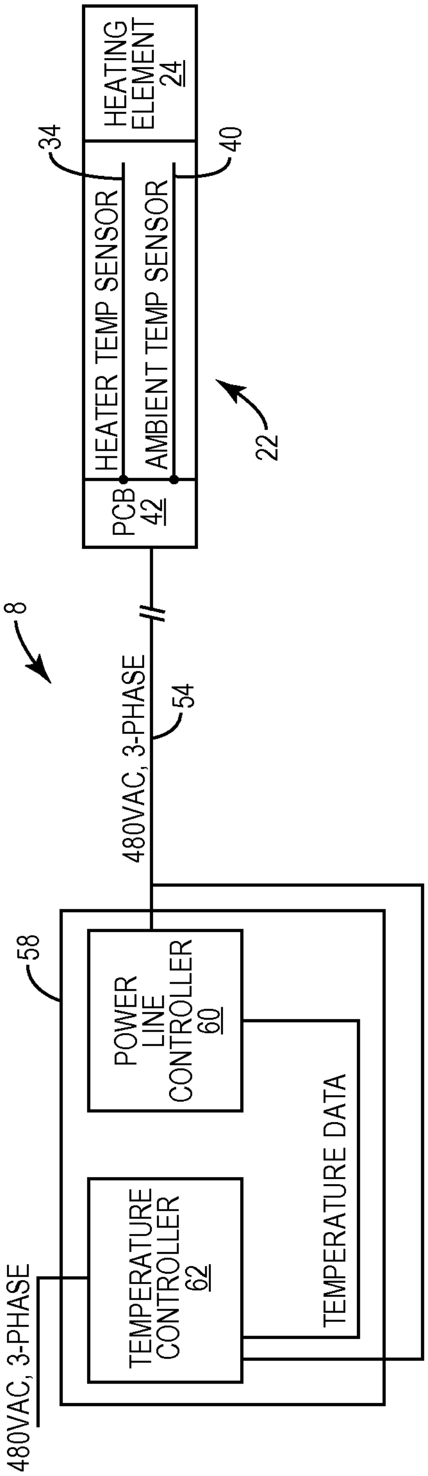

HEATING ELEMENT 24
34
40
HEATER TEMP SENSOR
AMBIENT TEMP SENSOR
PCB 42
22
8
480VAC, 3-PHASE
54
58
POWER LINE CONTROLLER 60
TEMPERATURE CONTROLLER 62
TEMPERATURE DATA
480VAC, 3-PHASE

FIG. 3

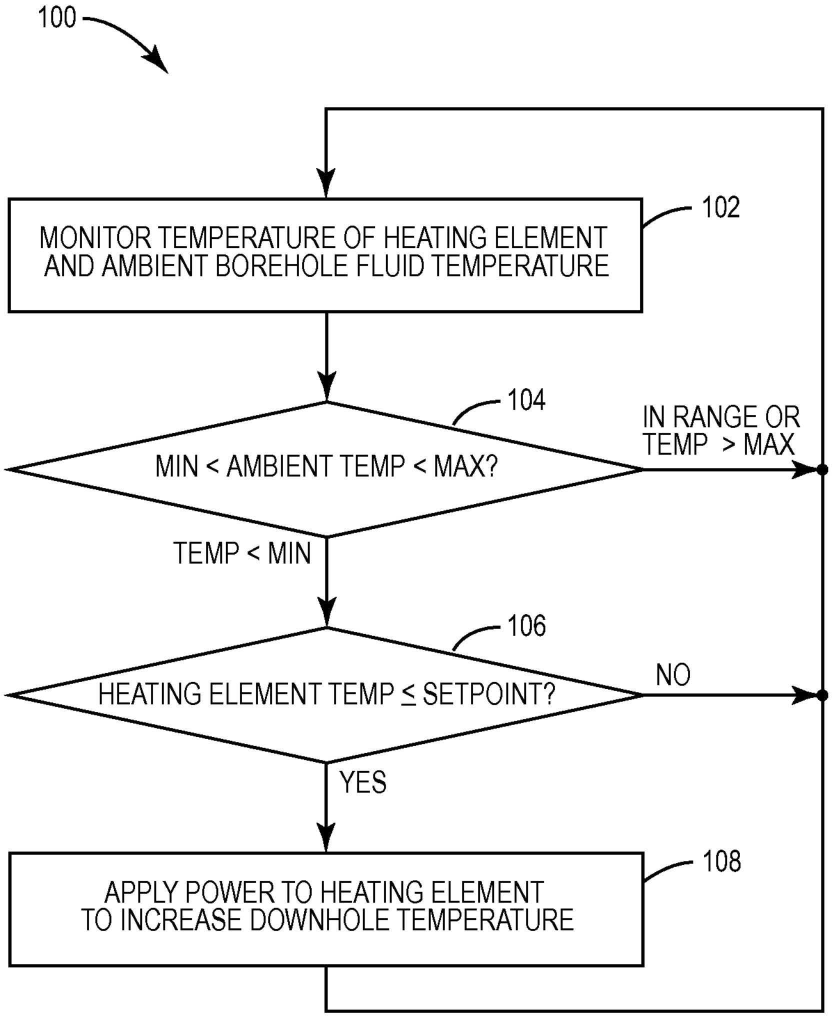

100
MONITOR TEMPERATURE OF HEATING ELEMENT AND AMBIENT BOREHOLE FLUID TEMPERATURE
102
MIN < AMBIENT TEMP < MAX?
104
IN RANGE OR TEMP > MAX
TEMP < MIN
HEATING ELEMENT TEMP ≤ SETPOINT?
106
NO
YES
APPLY POWER TO HEATING ELEMENT TO INCREASE DOWNHOLE TEMPERATURE
108

FIG. 4

DOWNHOLE HEATER ASSEMBLY AND POWER LINE COMMUNICATIONS SYSTEM

[0001] This application claims priority to U.S. Provisional Patent Application Ser. No. 61/703,477, titled "Downhole Heater Assembly and Power Line Communications System," filed Sep. 20, 2012, the disclosure of which is incorporated herein by reference in its entirety.

FIELD OF INVENTION

[0002] The present invention relates generally to subsurface hydrocarbon extraction, and in particular to a downhole heater assembly and method of temperature communications.

BACKGROUND

[0003] Hydrocarbon (e.g., crude oil and natural gas) extraction from subsurface formations is a costly and complex endeavor. After drilling, a well is cased, and tubing is installed in the borehole to carry the target fluids to the surface. If the subsurface pressure is insufficient to flow the oil and gas to the surface, as is the case in many wells that have been in production for some time, a pump is required to pump the fluids out. In many cases, particularly in older wells, the remaining hydrocarbons have such low viscosity, or are clogged with paraffin or other substances, that pumping is inefficient or impossible. In the case of natural gas, iron oxides and other residues may build up and impede the free flow of gas.

[0004] It is known in the art to position a heating element downhole, to increase the temperature and hence lower the viscosity of hydrocarbons, melt interfering paraffin, break up concentrations of iron oxides or other residues, and generally facilitate efficiently pumping hydrocarbons to the surface. For example, U.S. Pat. No. 7,363,979 discloses a downhole heater and system of rugged electrical connectors necessary to survive the downhole environment. Proper control of such a downhole heater is essential to optimally heating the downhole fluids. However, control of a downhole heater is complicated by the need to transmit temperature data to the surface for monitoring and control.

[0005] The Background section of this document is provided to place embodiments of the present invention in technological and operational context, to assist those of skill in the art in understanding their scope and utility. Unless explicitly identified as such, no statement herein is admitted to be prior art merely by its inclusion in the Background section.

SUMMARY

[0006] The following presents a simplified summary of the disclosure in order to provide a basic understanding to those of skill in the art. This summary is not an extensive overview of the disclosure and is not intended to identify key/critical elements of embodiments of the invention or to delineate the scope of the invention. The sole purpose of this summary is to present some concepts disclosed herein in a simplified form as a prelude to the more detailed description that is presented later.

[0007] According to one or more embodiments described and claimed herein, a hydrocarbon heating system comprises a surface control panel and a subsurface heating system, connected by an external power cable which also serves as the data communication link between the two parts. The subsurface heating system includes a heating element and two separate, thermally isolated temperature sensors. One thermal sensor, mounted near the heating element, monitors the temperature of the heating element, to ensure that it operates within an optimal temperature range, and to prevent damage from overheating. Another thermal sensor, preferably isolated from the heating element sensor, monitors the ambient temperature in the well. The temperature of the heating element may be varied to maintain an optimal well temperature for the production of hydrocarbons. Downhole electronics convert the thermal sensor outputs to digital data, and modulate the digital data onto a power cable that carries power from the surface to the heating element. A control system at the surface controls the heating element via nested control loops monitoring the temperatures of the borehole fluid and the heating element.

[0008] One embodiment relates to a downhole hydrocarbon heating system operative to heat hydrocarbon fluids in an oil or gas well comprising a borehole. The system includes a surface control panel and a subsurface heating system operative to be deployed down the borehole. The subsurface heating system includes a heating element; a first thermal sensor operative to sense the temperature of the heating element; and a second thermal sensor operative to sense the ambient temperature of fluid in the borehole. The system further includes a power cable connecting the surface control panel and the subsurface heating system. The power cable is operative to selectively carry power from the surface control panel to the heating element. The power cable is further operative to carry temperature data from the first and second thermal sensors to the surface control panel.

[0009] Another embodiment relates to a method of controlling the temperature of hydrocarbons in a well comprising a borehole. Disposed in the borehole is a subsurface heating system including a heating element, a first thermal sensor operative to sense the temperature of the heating element, and a second thermal sensor operative to sense the ambient temperature of fluid in the borehole. The temperature of the heating element and the ambient temperature of fluid in the borehole are monitored. Power is applied to the heating element in response to the sensed ambient temperature of fluid in the borehole being below a lower limit, and the sensed temperature of the heating element being below a setpoint. Power is removed from the heating element in response to the sensed ambient temperature of fluid in the borehole being above an upper limit or between the lower and upper limit, or the sensed temperature of the heating element being above the setpoint.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. However, this invention should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

[0011] FIG. **1** is a sectional diagram of a producing oil well with a downhole heating and control system according to one embodiment of the present invention.

[0012] FIG. **2** is a more detailed sectional view of the downhole heating and control system according to one embodiment of the present invention.

[0013] FIG. **3** is a functional block diagram of a temperature sensor control and communication system according to one embodiment of the invention.

[0014] FIG. **4** is a flow diagram of a method of controlling the temperature of hydrocarbons in a well.

DETAILED DESCRIPTION

[0015] It should be understood at the outset that although illustrative implementations of one or more embodiments of the present disclosure are provided below, the disclosed systems and/or methods may be implemented using any number of techniques, whether currently known or in existence. The disclosure should in no way be limited to the illustrative implementations, drawings, and techniques illustrated below, including the exemplary designs and implementations illustrated and described herein, but may be modified within the scope of the appended claims along with their full scope of equivalents.

[0016] FIG. **1** depicts a modern, mature, production oil well the well **10** comprises a borehole **12** in which production tubing **14** has been installed. A pump jack **16** creates a pressure differential that pulls hydrocarbons from a subsurface production zone **18** into the borehole **12**. The hydrocarbons enter the production tubing **14** through a perforated section **20**, and are pumped to the surface. In many cases, the hydrocarbon fluids are of low viscosity, clogged with paraffin or iron oxides, or otherwise present obstructions to efficient pumping. In these cases, a hydrocarbon heating system **8** according to one or more embodiments of the present invention may be deployed to heat the fluids. The hydrocarbon heating system **8** comprises two parts: a surface control panel **58** and a subsurface heating system **22**, connected by an external power cable **54** which also serves as the data communication link between the two parts.

[0017] The subsurface heating system **22**, depicted in greater detail in FIG. **2**, is attached to the downhole side of production tubing **14**, below the perforated section **20**. The core of the subsurface heating system **22** is a heating element **24**. The heating element **24** is a long, thin element, e.g., in one embodiment, approximately ten feet in length and less than one inch in diameter. The heating element **24** is disposed in a lower housing **26**, such as a section of 2.5 inch stainless steel pipe. The heating element **24** is generally centered within the lower housing **26**, and is preferably held in position by thermally conductive cement **28**, such as ceramic heat transfer cement. In operation, the lower housing **26** is disposed in the borehole **12** at a target depth corresponding to the subsurface production zone **18**, to heat the hydrocarbon fluids. In one embodiment, upper and lower standoffs **30** welded to the exterior of lower housing **26** maintain the lower housing **26** generally centered within the borehole **12**. In one embodiment, the lower housing **26** is approximately ten feet in length.

[0018] One example of a suitable heating element **24** is a 12 kW Maxizone heater, available from Chromalox of Pittsburgh, Pa. The heating element **24** preferably operates in the range of 500-600 degrees Fahrenheit (F). The heating element **24** is powered, in one embodiment, by a three-phase, 12-gauge, Teflon stranded internal power cable **32** carrying, e.g., 480 VAC, 3-phase power obtained from the surface control panel **56** via external power cable **54**. A first thermal sensor **34**, such as a K type thermocouple, is embedded in, or disposed proximate to, the heating element **24**. The first thermal sensor **34** monitors the temperature of the heating element **24**.

[0019] In one embodiment, an insulating section **36** separates the lower housing **26** from the upper housing **38**. The insulating section **36** ensures separation between the heating element **24** and control electronics and a second sensor **40** housed in the upper housing **38**. In one embodiment, the insulating section **38** is in the range of eight to ten feet long. This distance allows the second sensor **40** to monitor the ambient temperature of fluids in the borehole **12**, without undue influence from the heating element **24**. The internal power cable **32** passes through the insulating section **36**.

[0020] An upper housing **38**, disposed opposite the insulating section **36** from the lower housing **26**, includes downhole printed circuit board (PCB) **42**, which contains the downhole control electronics. The downhole PCB **42** is powered from the internal power cable **32** via a transformer **44**. A second thermal sensor **40** is disposed in the upper housing **38**, and connected to the downhole PCB **42**. The second thermal sensor **40** is operative to monitor the ambient temperature of fluids in the borehole **12**, which are preferably maintained in the range of 150-200 degrees F., and more preferably in the range of 160-180 degrees F. The transformer **44**, PCB **42**, second thermal sensor **40**, and power cable **32** are preferably encased in an inert compound **46**. The transformer **44** and PCB **42** may comprise any suitable components—for example, components designed and certified for use in harsh environments. In one embodiment, separation of the second thermal sensor **40** from the heating element **24** is provided, not by a separate insulating section **36**, but by locating the second thermal sensor **40** in the upper region of the upper housing **38**. In this embodiment, the upper housing **38** is preferably eight to ten feet long.

[0021] Above the upper housing **38**, a cable admission connector **48**, connected thereto by a coupler **47**, includes a port **50**, to which is attached a connector **52**. The connector **52** provides a quick-detach connection between the internal power cable **32** providing power to the PCB **42** and heating element **24**, and an external power cable **54** that extends up the borehole **12** external to the production tubing **14**. The external power cable **54** is preferably an armored cable designed for operation in the harsh environment of the borehole **12**. One example of a suitable external power cable **54** is a 3×, 4 AWG flat armored cable available from Schlumberger of Houston, Tex.

[0022] The cable admission connector **48** connects to the upper housing **38**, via a coupler **47**, in a manner that excludes borehole fluids from the interior of the upper housing **38**. Indeed, from the coupler **47** downward, the system **22** is a sealed environment, with no incursion of borehole **12** fluids into the interior of the upper housing **38**, insulating section **36**, or lower housing **26**. One example of a suitable cable admission connector **48** is the ZPTC series connector available from Taurus Engineering of Long Beach, Calif. In one embodiment, the power cable **32** also carries temperature monitoring signaling from the downhole thermal sensors **34**, **40** to the surface, as described further herein.

[0023] Above the cable admission connector **48**—which constitutes the upper extent of the subsurface heating system **22**—is a perforated tubing section **20**. The perforated tubing section **20** is the lower-most portion of the production tubing **14**, and may be, for example, four feet long. Perforations in the perforated tubing section **20** allow hydrocarbon fluids to enter the production tubing **14**, where they are pumped to the surface by the pump jack **16**. Intermittently, such as at intervals of 30 feet, straps **56** secure the exterior power cable **54** to the production tubing **14**. The straps may be applied, as required or desired, as the subsurface heating system **22** and production tubing **14** are lowered into the borehole **12**. At the surface, the external power cable **54** enters a control panel **56**, which houses the surface electronics.

[0024] In general, the sections of the subsurface heating system **22**—such as the lower housing **26**, insulating section **36**, and upper housing **38**—may be constructed from 2.5 inch steel pipe with National Pipe Thread Taper (NPT), coupled together by 2 inch×2.5 inch NPT couplers, as well known in the drilling and hydrocarbon production arts.

[0025] The first thermal sensor **34** monitors the temperature of the heating element **24**, and the second thermal sensor **40** monitors the ambient borehole fluid temperature. Both thermal sensors **34**, **40** are connected to the downhole PCB **42**, which converts the thermal sensor **34**, **40** voltages to digital temperature data, and transmits the temperature data to the surface control panel **56** using power line communications.

[0026] FIG. **3** presents a functional block diagram of the electrical and control system of the hydrocarbon heating system **8**. The subsurface heating system **22** comprises the heating element **24**, first thermal sensor **34** monitoring the heating element **24**, second thermal sensor **40** monitoring the ambient borehole fluid temperature, and the downhole PCB **42**. The PCB **42** is powered by a transformer **44** connected to the internal power cable **32**. The PCB also connects across two phases of the internal power cable **32** to communicate temperature data to the surface control panel **58** via power line communications. The coupling across two phases obviates the need for a neutral, or ground, conductor.

[0027] The PCB **42** includes a power line controller operative to modulate digital data on a power line for communication to the surface control panel **58**. One example of a suitable power line controller is a PL3120 power line smart transceiver, available from Eschelon Corp. of San Jose, Calif. The PL3120 includes a power line transceiver, a Neuron processor core, embedded memory, and associated circuits. The PCB **42** additionally includes two Analog to Digital Converters (ADC) to convert the output voltages of the thermal sensors **34**, **40** to digital values. One example of a suitable ADC is a MAX31855 cold-junction compensated thermocouple-to-digital converter, available from Maxim Integrated Products of San Jose, Calif. The ADCs communicate with the power line controller, such as via an I2C interface.

[0028] In one embodiment, the thermal sensor **34**, **40** values are converted to Lonworks protocol Standard Network Variable Type (SNVT) temperature values. As known in the art, Lonworks is an industry standard networking protocol targeted to address the needs of control applications. The Lonworks protocol defines a plurality of SNVTs for common control system variable types. For example, the temperature SNVT defines a number between zero and 65535 that corresponds to a temperature between −247 and 6279.5 degrees Celsius. The Lonworks protocol also defines the standards for power line communications, by which digital data is modulated onto an AC power line.

[0029] The surface control panel **56** includes also includes a power line controller **60** operative to extract thermal **34**, **40** data from the external power cable **54**. The surface power line controller **60** be the same as, or similar to, the power line controller on the downhole PCB **42**. In one embodiment, the surface power line controller **60** converts the temperature data from the subsurface heating system **22** into two 4-20 ma current loop signals for use as feedback signals for two nested temperature control loops, controlled by a temperature controller **62**. An inner control loop prevents the heating element **24** from operating beyond a maximum setpoint, such as 600 degrees F. An outer control loop modulates power to the heating element **24** to maintain a desired ambient downhole fluid temperature, such as in the range of 150-200 degrees F., and more preferably in the range of 160-180 degrees F. The temperature controller **62** controls the downhole temperatures by modulating the 480 VAC, 3-phase power to the heating element **24**, such via a solid state 3-phase relay. In one embodiment, regardless of the control loop outputs, downhole power is periodically applied for a brief duration—such as for two seconds every thirty seconds—to allow the subsurface heating system **22** to obtain and transmit updated temperature readings. One example of a suitable temperature controller **62** is an EZ-Zone PM controller, available from Watlow Electric Manufacturing Co. of St. Louis, Mo.

[0030] FIG. **4** depicts a method **100** of controlling the temperature of hydrocarbons in a well. Although those of skill in the art will appreciate that the method describes a continuous and ongoing process, for the purpose of explanation it may be said to "begin" by monitoring the temperature of the heating element **24**, via the first thermal sensor **34**, and the ambient borehole fluid temperature, via the second thermal sensor **40** (block **102**). The ambient borehole fluid temperature is controlled in an outer control loop (block **104**). If the ambient temperature is within a predetermined range, such as 150-200 degrees F., or more preferably 160-180 degrees F., or if the ambient temperature exceeds the maximum desired temperature, the heating element **24** is not energized, and the system **8** continues to monitor the downhole temperatures (block **104**). If the ambient borehole fluid temperature falls below the desired minimum temperature, then the heating element **24** is energized to further heat the hydrocarbons, subject to the operation of the inner control loop. If the temperature of the heating element **24** is at or below a predetermined setpoint (block **106**), then the heating element **24** is energized by supplying 480 VAC, 3-phase power via the external power cable **54** and internal power cable **32** (block **108**). However, if the temperature of the heating element **24** exceeds its setpoint (block **106**), then the heating element **24** is not energized, regardless of the ambient borehole fluid temperature, to prevent damage to the heating element **24**. In either case, the system **8** then continues to monitor the downhole temperatures (block **102**).

[0031] Those of skill in the art will recognize that the method **100** as depicted in FIG. **4** is representative only, and many variations are possible within the scope of the present invention. For example, in one embodiment, once the ambient borehole fluid temperature is within the desired range, a partial current may be supplied to the heating element **24** to maintain its temperature, with the power being removed only if the first thermal sensor **34** indicates a temperature above the setpoint. As another example, as discussed above, even when the heating element **24** is not energized by the control loops (i.e., method block **108** is not reached due to the downhole temperatures reported), the power may be applied periodically for brief durations (e.g., two seconds every thirty seconds) to energize the downhole electronics and obtain updated temperature readings. Furthermore, various timers may be implemented to halt the method **100** in a state (e.g., block **108**) for predetermined durations. In general, those of skill in the art may devise numerous temperature control schemes, given the teachings of the present disclosure and the resources of two separate, independent thermal sensors **34**, **40** reporting both heating element **24** and ambient borehole fluid temperatures, respectively. All such heating element **24** control schemes would fall within the broad scope of the present invention.

[0032] The hydrocarbon heating system **8** of the present invention presents numerous advantages over the prior art. By providing two temperature sensors **34**, **40** in the subsurface system **22**, two critical temperatures may be monitored. By controlling the heating element **24** in a nested control loop, the ambient borehole fluid temperature may be regulated as desired, subject to the protective monitoring and control function of limiting the temperature of the heating element **24**. By employing power line communications to convey temperature readings from the subsurface thermal sensors **34**, **40** to the surface, the need for expensive and fragile dedicated communication lines is obviated. This improves both lowers cost and improves the reliability of operation in the hostile environment of the borehole **12**.

[0033] The present invention may, of course, be carried out in other ways than those specifically set forth herein without departing from essential characteristics of the invention. The present embodiments are to be considered in all respects as illustrative and not restrictive, and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.

What is claimed is:

1. A downhole hydrocarbon heating system operative to heat hydrocarbon fluids in an oil or gas well comprising a borehole, the system comprising:

a surface control panel;

a subsurface heating system operative to be deployed down the borehole and including

a heating element;

a first thermal sensor operative to sense the temperature of the heating element; and

a second thermal sensor operative to sense the ambient temperature of fluid in the borehole; and

a power cable connecting the surface control panel and the subsurface heating system, the power cable operative to selectively carry power from the surface control panel to the heating element, and further operative to carry temperature data from the first and second thermal sensors to the surface control panel.

2. The system of claim **1** wherein the heating element and the first thermal sensor are disposed in a lower housing operative to be deployed in the borehole at the depth of a hydrocarbon production zone.

3. The system of claim **1** wherein the heating element is disposed centrally in the lower housing and secured by a thermally conductive concrete.

4. The system of claim **1** wherein the lower housing comprises standoff elements secured to the exterior thereof in radially spaced positions, the standoff elements operative to maintain the lower housing generally centered in the borehole.

5. The system of claim **1** wherein the second thermal sensor is disposed in a spaced relationship with the heating element such that the temperature sensed by the second thermal sensor is not directly influenced by the heating element.

6. The system of claim **5** wherein the subsurface heating system further comprises an insulating section interposed between the heating element and the second thermal sensor.

7. The system of claim **1** wherein the subsurface heating system further comprises a downhole printed circuit board (PCB) containing electronics to convert the first and second thermal sensor outputs to digital data, and to modulate the digital temperature data onto the power cable.

8. The system of claim **7** further comprising a transformer operative to tap power from the power cable and to power the downhole PCB.

9. The system of claim **7** wherein power cable carries 3-phase power, and wherein the electronics on the downhole PCB are operative to modulate digital data across two phases of the power cable.

10. The system of claim **1** wherein the subsurface heating system is deployed below production tubing operative to extract hydrocarbons from the well.

11. The system of claim **1** wherein the surface control panel comprises:

a power line controller operative to receive sensed temperature data from the power cable; and

a temperature controller operative to control power to the heating element by selectively connecting the power cable to a power source in response to the sensed temperature data received from the power line controller.

12. The system of claim **10** wherein the temperature controller is operative to control power to the heating element by:

in an outer control loop, applying power to the heating element in response to the ambient temperature of fluid in the borehole being below a predetermined lower limit; and

in an inner control loop, applying power to the heating element only if the temperature of the heating element is at or below a predetermined setpoint, without regard to the outer control loop.

13. The system of claim **10** wherein the temperature controller is operative to control power to the heating element by periodically applying power to the heating element for brief durations without regard to the ambient fluid or heating element temperature values.

14. A method of controlling the temperature of hydrocarbons in a well comprising a borehole, in which is disposed a subsurface heating system including a heating element, a first thermal sensor operative to sense the temperature of the heating element, and a second thermal sensor operative to sense the ambient temperature of fluid in the borehole, the method comprising:

monitoring the temperature of the heating element and the ambient temperature of fluid in the borehole;

applying power to the heating element in response to the sensed ambient temperature of fluid in the borehole being below a lower limit, and the sensed temperature of the heating element being below a setpoint; and

removing power from the heating element in response to the sensed ambient temperature of fluid in the borehole being above an upper limit or between the lower and upper limit, or the sensed temperature of the heating element being above the setpoint.

15. The method of claim **11**, further comprising

periodically applying power to the heating element for brief durations without regard to the values sensed by the first and second thermal sensors.

16. The method of claim **12** wherein periodically applying power to the heating element for brief durations comprises applying power to the heating element for two seconds every thirty seconds.

* * * * *