US 20180059325A1

(19) United States
(12) Patent Application Publication
Anderson et al.
(10) Pub. No.: US 2018/0059325 A1
(43) Pub. Date: Mar. 1, 2018

(54) **OPTICAL FIBER THERMAL PROPERTY PROBE**

(71) Applicant: **Wisconsin Alumni Research Foundation**, Madison, WI (US)

(72) Inventors: **Mark Harlan Anderson**, Oregon, WI (US); **Matthew Thomas Weathered**, Naperville, IL (US)

(21) Appl. No.: **15/671,291**

(22) Filed: **Aug. 8, 2017**

Related U.S. Application Data

(60) Provisional application No. 62/381,324, filed on Aug. 30, 2016.

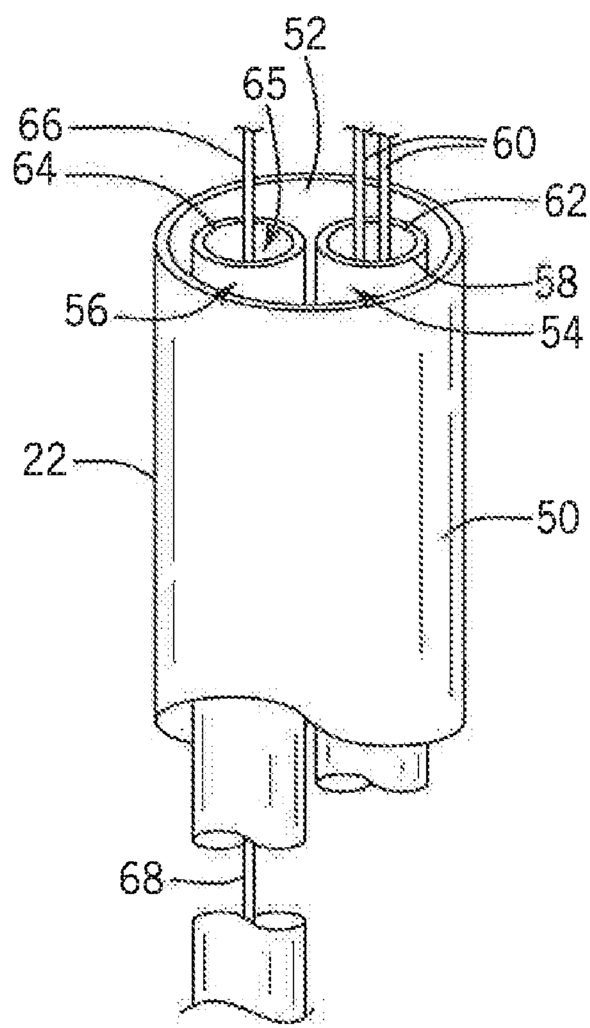
Publication Classification

(51) **Int. Cl.**
G02B 6/287 (2006.01)
B29C 65/16 (2006.01)
G02B 6/02 (2006.01)
C03B 37/15 (2006.01)
G02B 6/27 (2006.01)
C03B 37/025 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/287*** (2013.01); ***B29C 65/16*** (2013.01); ***C03B 37/0253*** (2013.01); ***C03B 37/15*** (2013.01); ***G02B 6/272*** (2013.01); ***G02B 6/02395*** (2013.01)

(57) **ABSTRACT**

An optical fiber sensor extends coaxially with a controllable heater to provide high-resolution axial measurement of thermal properties such as thermal convection of the surrounding, Heat removal by either conduction or convection may be used to deduce material height in a tank, or velocity of flow when coupled with localized heating, or other aspects of the material based on thermal conductivity.



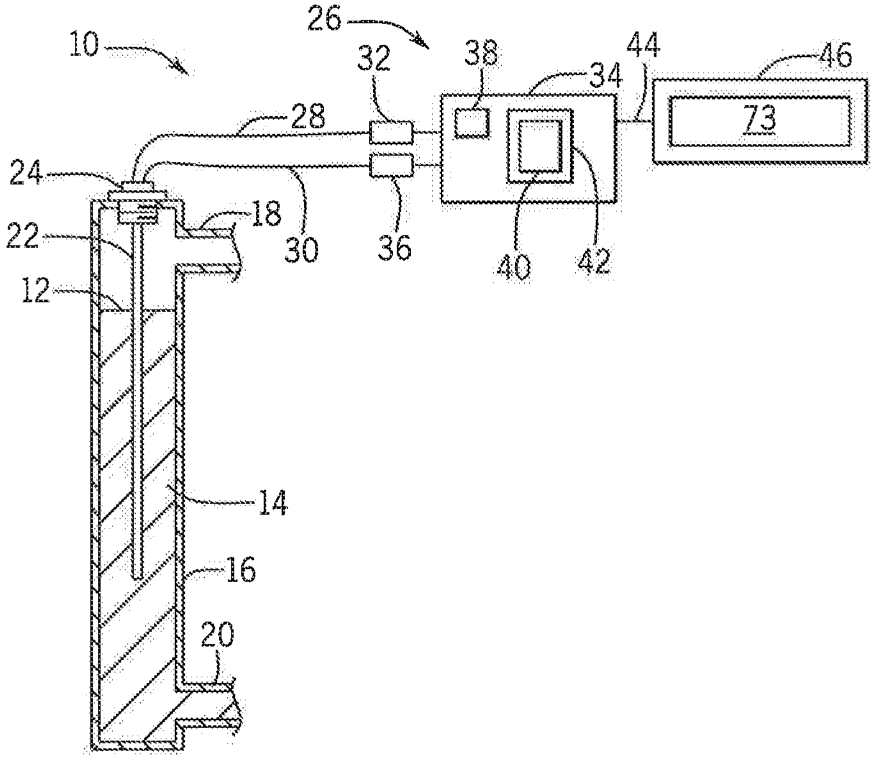

10
26
32
38
34
44
46
73
28
24
18
22
30
36
40
42
12
14
16
20

FIG. 1

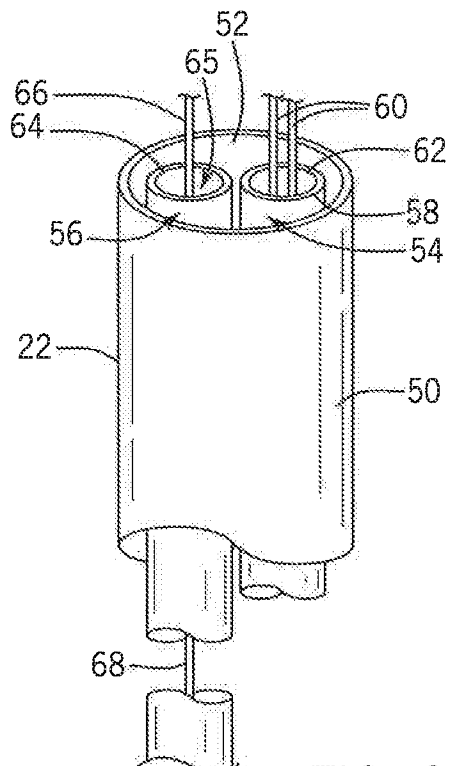

52
65
66
60
64
62
58
56
54
22
50
68

FIG. 2

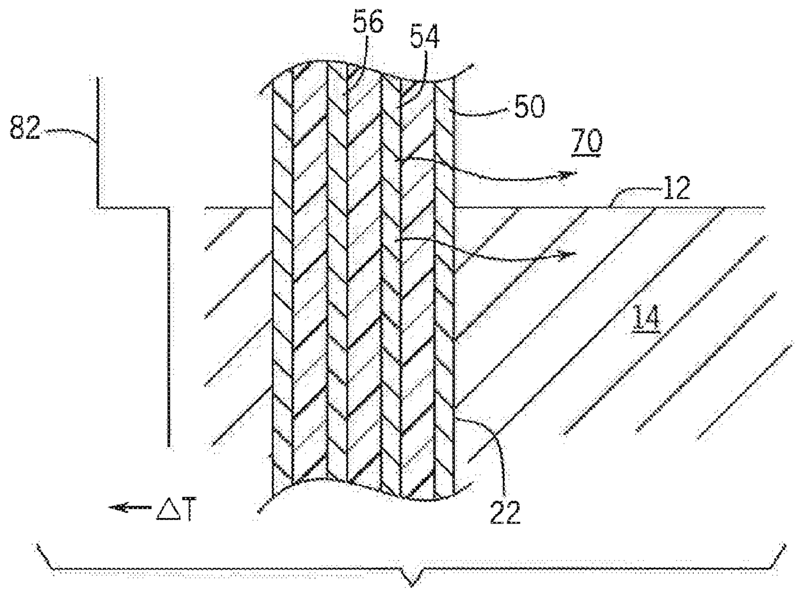


FIG. 3

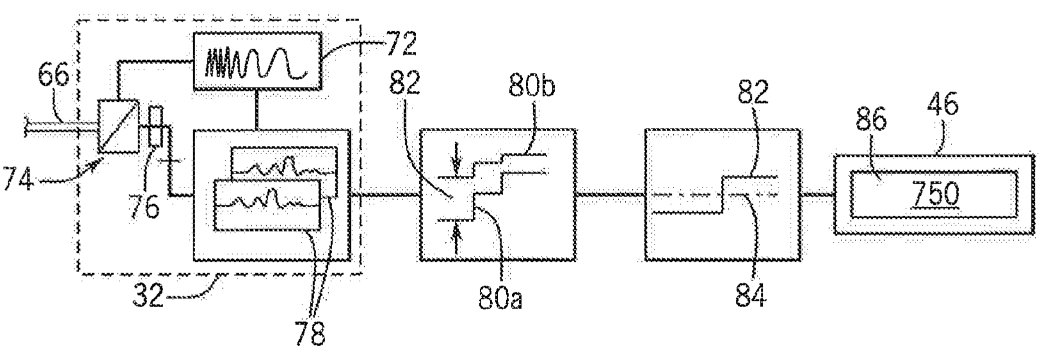


FIG. 4

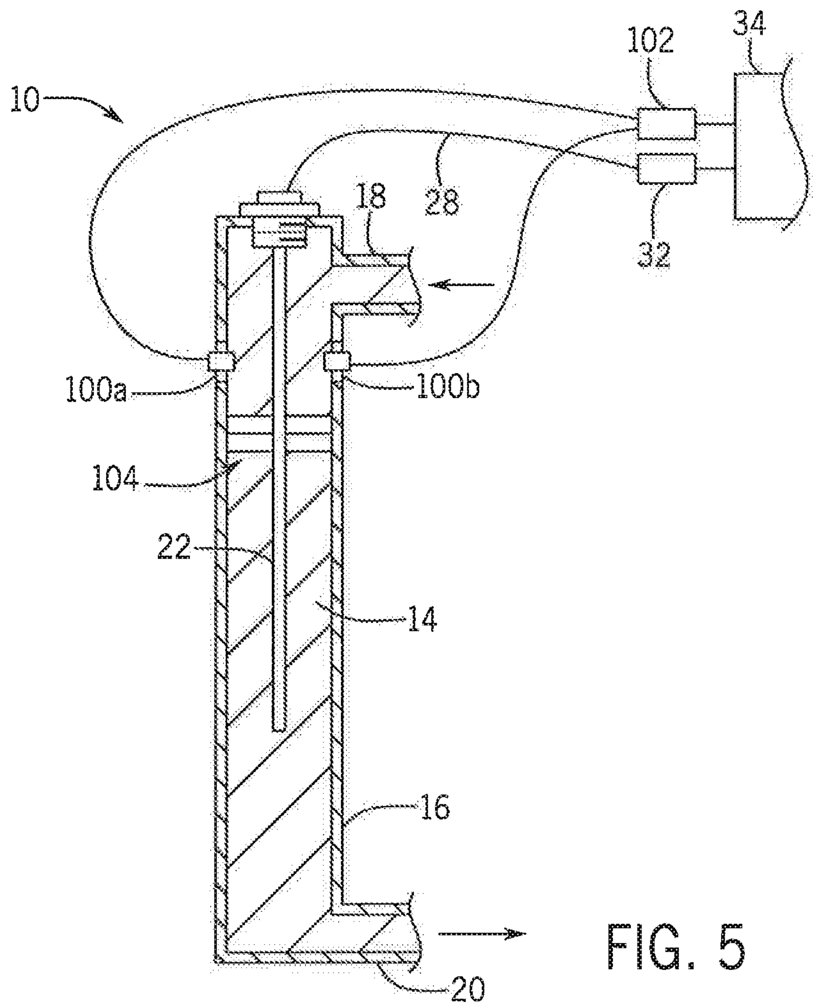

10
102
34
28
18
32
100a
100b
104
22
14
16
20

FIG. 5

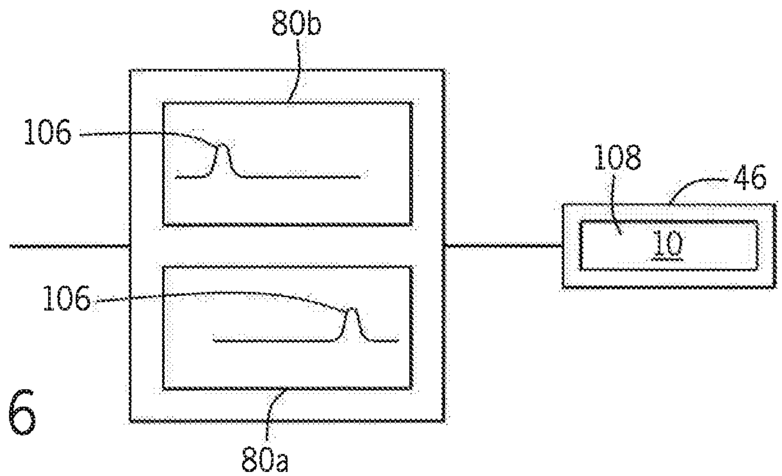

80b
106
108
46
10
106
80a

FIG. 6

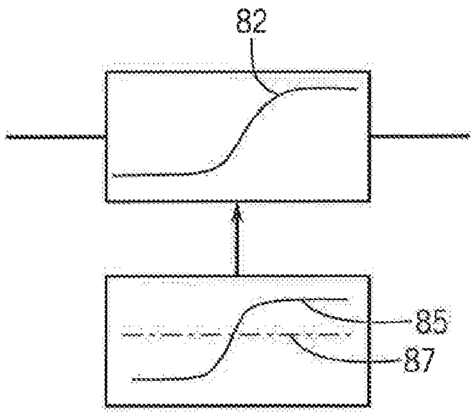


FIG. 7

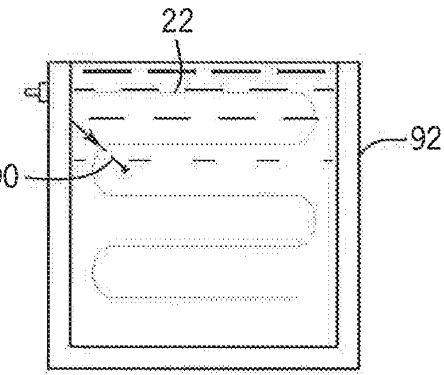


FIG. 8

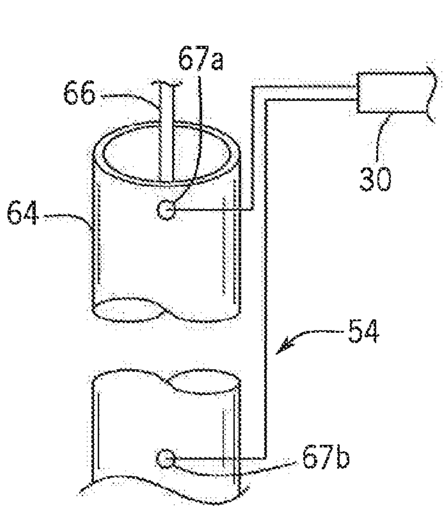


FIG. 9

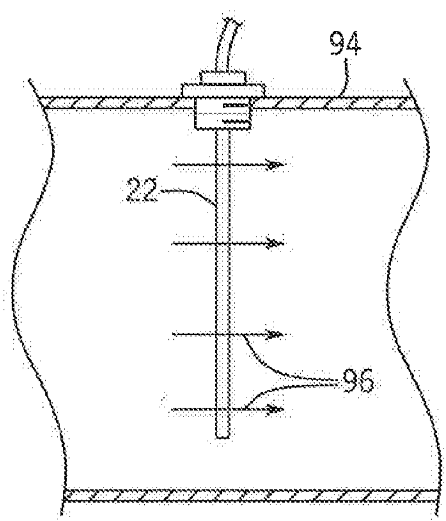


FIG. 10

OPTICAL FIBER THERMAL PROPERTY PROBE

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. provisional application Ser. No. 62/381,324 filed Aug. 30, 2016 and hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to an optical fiber probe, and in particular, to an optical fiber probe that can sense thermal properties of the surrounding medium.

[0003] Next generation (generation IV) nuclear reactors such as the Sodium Fast Reactor (SFR) employ alkali liquid metal (e.g., sodium) as a coolant carrying heat from the reactor core. Critical for the construction of such reactors is an ability to provide instrumentation that can measure level, temperature, and velocity distributions in a material such as liquid sodium or fuel at temperatures above 371 Kelvin.

[0004] Normal instrumentation, for example, for level sensing, including ultrasonic and mechanical approaches, can be prone to failure in such extreme operating environments,

SUMMARY OF THE INVENTION

[0005] The present invention provides an optical fiber linked with a heater allowing it to characterize thermal properties of nearby materials at multiple points along the fiber at extremely high temperatures associated with nuclear reactors or heat storage systems. Measurements by the system may determine material levels (such as the level of liquid sodium or similar transfer or storage material) by detecting changes between the thermal properties of the material and an overlying gas column, or measure rates of flow when coupled with localized heating, or characterize nuclear fuel during use or the like.

[0006] Specifically, the invention provides a sensor system for characterizing material thermal properties and includes an optical fiber, a heater strip coextending with the optical fiber, an optical assembly for transmitting light into the optical fiber and detecting light received from the optical fiber, and an electronic circuit communicating with the optical assembly and the heater strip to: (a) characterize temperature at multiple points along a length of the optical fiber from the light received from the optical fiber as influenced by the heat output from the heater strip; and (b) determine and output a measure related to thermal property of a medium surrounding the optical fiber and heater strip.

[0007] It is thus a feature of at least one embodiment of the invention to provide sophisticated multipoint analysis of thermal conductivity of materials such as can be used for a variety of sensing purposes.

[0008] The sensor system may include a thermally conductive shield around the optical fiber.

[0009] It is thus a feature of at least one embodiment of the invention to permit use of the sensor system in hostile environments such as in liquid sodium, molten salts, or other organic and inorganic substances.

[0010] The conductive shield may be a stainless-steel tube filled with a fluid conductive medium positioned between an inner wall of the stainless-steel tube and the optical fiber.

[0011] It is thus a feature of at least one embodiment of the invention to provide robust shielding of the optical fiber that prevents thermal stresses caused by engagement between the fiber and the tube while promoting high thermal conductivity.

[0012] The conductive medium may be a moisture-free gas such as helium and the conductive shield may be hermetically sealed.

[0013] it is thus a feature of at least one embodiment of the invention to provide a shielding system that can accommodate extreme temperature variations without damage to the optical fiber.

[0014] The sensor system may provide a sheath surrounding the optical fiber and the heater strip including a conductive potting material holding the heater strip and optical fiber in thermal proximity.

[0015] It is thus a feature of at least one embodiment of the invention to provide a robust assembly that can produce consistent measurement results by close thermal linking between the heater and the optical fiber.

[0016] The heater strip may be a resistive wire element providing substantially uniform distributed heating along the length of the heater strip.

[0017] It is thus a feature of at least one embodiment of the invention to provide a uniform and constant heating to simplify the determination of thermal properties such as thermal conductivity or thermal convection.

[0018] These particular objects and advantages may apply to only some embodiments falling within the claims and thus do not define the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. **1** is a cross-sectional view of a level sensor for liquid heat storage material employing the present invention providing a vertically extending probe passing through a surface of the liquid heat storage material and communicating with a reflectometer system;

[0020] FIG. **2** is a fragmentary perspective view of the probe of Fig, **1** showing parallel extending optical fiber and heater elements within a probe sheath;

[0021] FIG. **3** is a fragmentary cross-section of the probe of FIG. **2** showing the use of the heater element to reveal thermal conductivity of the environment of the probe;

[0022] FIG. **4** is a signal flow diagram describing a program executed by the reflectometer of FIG. **1**;

[0023] FIG. **5** is a fragmentary figure similar to FIG. **1** showing the use of the probe for flow velocity sensing;

[0024] FIG. **6** is a fragmentary view similar to that of FIG. **4** showing comparison of temperatures at different times to deduce flow velocity;

[0025] FIG. **7** is a fragmentary view of the signal flow diagram of FIG. **4** showing a curve-fitting process;

[0026] Fig, **8** is a figure showing curvature of the probe to provide multiple measurement points over an area and/or volume;

[0027] FIG. **9** is a fragmentary view of an alternative embodiment of the probe in which the fiber optic shield provides the heater element; and

[0028] FIG. **10** is an alternative application of the probe for providing multipoint flow measurements.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0029] Referring now to FIG. **1**, a sensor system **10** of the present invention may be used, for example, to determine a height of a surface level **12** of a heat storage material **14** such as liquid sodium or other liquid metals or salts such as but not limited to $NaNO_3KNO_3$ salts and FLIBE salts (lithium fluoride and beryllium fluoride) up to 600 C. This heat storage material **14** may be held within an accumulator **16**, for example, the accumulator **16** providing a vertically extending enclosed container communicating through inlet **18** and outlet **20** at the upper and lower ends of the accumulator **16** with elements of a nuclear reactor or the like. The sensor system **10** includes a vertically extending probe **22**, for example, attached to penetrate an upper wall of the accumulator **16** through a sealing fitting **24** and pass downward through the surface level **12** into the heat storage material **14** within the accumulator **16**.

[0030] A proximal end of the probe **22** outside of the accumulator **16** may connect to a reflectometer system **26** through optical conductor **28** (such as an optical fiber). Optical conductor **28** may be received by an optical assembly **32** (as will be described below) communicating in turn with an electronic computer **34**. The proximal end of the probe **22** may also receive electrical signals communicated through electrical conductor **30** with a controllable power source **36** controlled by the computer **34**.

[0031] Computer **34** may include one or more processors **38** executing a program **40**, as will be discussed below, held in standard computer memory **42**. The computer **34** may provide an output **44**, for example, communicating with a display **46** which may display a number indicating a height of the liquid heat storage material **14** in the accumulator **16** or, as will be discussed in a. further embodiment below, a velocity of movement of the fluid **14** or other thermal characteristics of material in contact with the probe **22** Alternatively, it will be appreciated that the display may indicate other thermal properties such as convection, thermal conductivity or the like and may be in a variety of different units or unitless.

[0032] A reflectometer system **26** providing the optical assembly **32** and optionally portions of the electronic computer **34** and suitable for use with the present invention is commercially available from Luna of Roanoke, Va., USA, under the tradename of Luna ODiSI-B Optical Distributed Sensor Interrogator.

[0033] Referring now also to FIG. **2**, the probe **22** may provide for a generally linearly extending outer sheath **50**, for example, in the form of a stainless-steel tube. Positioned within the outer sheath **50** and extending therealong may be an elongate heater element **54** and an optical fiber assembly **56**, each generally adjacent to and parallel to the other and axially aligned within the sheath **50** to extend along a length of the sheath by a distance sufficient to pass above and below the surface level **12** over an expected range of heights of surface level **12**. The elongate heater element **54** and optical fiber assembly **56** may be fixed within the outer sheath **50** in a thermally conductive potting material **52**.

[0034] The heater element **54**, for example, may provide for an outer tubular sheath **58** of thermally conductive material (for example, metal) holding a resistive heating element **60** (for example, a high resistance electrical conductor such as nichrome) extending downward along the length of the probe **22** and looping backward to provide a complete electrical circuit. The resistive heating element **60** provides ohmic heating uniformly along its length and along the length of the optical fiber assembly **56** although predictable variability in ohmic heating along the length of the resistive heating element **60** can be accommodated, The resistive heating element **60** may connect via electrical conductor **30** to receive a constant current electrical flow from the controllable power source **36**. A space between the resistive heating element **60** and the tubular sheath **58** may be filled with an electrically insulating but thermally conductive potting material **62** for example a hardening ceramic powder or other material that can tolerate the necessary heat range. in alternative embodiments, the heating element **60** may extend downward through the probe **22** and the return electrical path may be provided through the sheath **50** or by separate conductor.

[0035] The optical fiber assembly **56** may provide for thermally conductive outer sheath **64**, for example, a stainless- steel or ceramic tube hermetically sealed at its lower and upper ends to retain within the sheath **64** atmosphere of moisture-free helium **65** or other highly thermally conductive gas. Ideally, the material within the sheath **64** will have a thermal conductivity equal or exceeding that of helium.

[0036] Positioned within the helium **65** is single mode optical fiber **66** having a center core and outer cladding of different refractive indexes to promote internal reflection. Significantly, the optical fiber **66** may be entirely glass material without a polymer or other coating normally used in such fibers such as could interfere with measurements at high temperatures, for example, by presenting a substantially different coefficient of expansion. In an alternative embodiment, a graphite coated fiber may be employed and polymer materials may be used for low temperature applications,

[0037] A lower end of the optical fiber **66** may be spliced to a dispersive fiber element **68**, for example, having only core material and no outer cladding to promote light leakage therefrom and thereby to eliminate high amplitude reflections from the end of the optical fiber **66**. Alternatively, the dispersive fiber elements **68** may be implemented using a portion of the optical fiber **66** curled into a tight radius to promote such light leakage.

[0038] As noted, the thermally conductive outer sheath **64** is hermetically sealed to prevent loss or contamination of the moisture-free helium **65** and to shield the optical fiber **66** from moisture. The optical fiber **66** is generally mounted, for example, only at the top end of the thermally conductive outer sheath **64** so as to prevent the introduction of stress in the fiber as the optical fiber **66** and thermally conductive outer sheath **64** expand and contract at different rates over the range of operating temperatures. In this way, the surrounding moisture-free helium **65** allows the necessary slippage between the optical fiber **66** and the sheath **64** in contrast, for example, to a rigid potting material

[0039] It will be appreciated that other materials than moisture-free helium **65** or other highly thermally conductive gases may be used such as provide freedom of movement of the optical fiber **66** and high thermal conductivity, including metals that retain a liquid state at room temperature.

[0040] Referring now to FIG. **9**, in an alternative embodiment, the heater element **54** may make use of the thermally conductive outer sheath **64** to provide an extremely low diameter probe **2.2** and one which reduces the thermal mass of the probe and improves coupling of the heater to the surrounding medium providing faster response. As depicted, the thermally conductive outer sheath **64** may be, for example, stainless steel having an electrical contact point **67***a* at its proximal end and an electrical contact point **67***b* at its distal end communicating with the electrical conductors **30** allowing a current to be passed along the length of the thermally conductive outer sheath **64** to produce ohmic heating. A similar approach may be used with a ceramic tube used for the thermally conductive outer sheath **64**, for example, by applying a conductive material such as a PTC coating to the thermally conductive outer sheath **64**. In that case, two parallel separate conductors may be used to allow a return path along the thermally conductive outer sheath **64**.

[0041] Referring now to FIG. **3**, the optical fiber assembly **56** may provide a measure of temperatures at multiple points along the optical fiber assembly **56** using reflectometer techniques as will be discussed below. When these temperature measurements are combined with an activation and deactivation of the heater element **54**, thermal properties of the environment of the probe **22** may be determined. For example, by comparing a change in temperature at a given location along the optical fiber assembly **56** between times of activation and deactivation of the heater element **54**, thermal conductivity of the surrounding material can be deduced. "Thermal properties" include actual thermal resistance and apparent thermal resistance (for example, influenced by convective flow, velocity, or the like). Thermal properties may be used to deduce material characteristics, interfaces between different states of material or different material types, flow velocity, convection, and the like.

[0042] Consider, for example, the environment of liquid heat storage material **14** below the surface level **12** and heated air **70** above the surface level **12**, When the heater element **54** is not activated, the temperatures measured by the optical fiber assembly **56** above and below the surface level **12** may be the same, reflecting a steady-state equilibrium in temperatures between the heat storage material **14** and the air **70**. Activation of the heater element **54**, however, may raise the temperature of the optical fiber assembly **56** in the region of the air **70** by more than the temperature is raised at the optical fiber assembly **56** in the region of liquid heat storage material **14** resulting from a greater thermal conductivity or thermal convection provided by the liquid heat storage material **14**. A temperature difference (delta T) **82** measured at multiple points along the length of the optical fiber assembly **56** with and without activation of the heater element **54** may thus reveal fundamental properties of the surrounding materials. More sophisticated measurements may look at the rise time or decay time of temperature when the heater is activated and deactivated and for example fit these measurements to a curve indicating thermal conductivity.

[0043] Referring now also to FIG. **4**, the optical assembly **32** may provide for a frequency controllable laser **72** operated by the computer **34**, for example, to sweep through light frequencies. This swept light is provided to beam splitter **74** coupling the light into the optical fiber **66**.

[0044] Within the optical fiber **66**, Rayleigh scattering in microscopic inclusions within the optical fiber **66** may cause reflections back through the optical fiber **66** through the beam splitter **74** to be received by photodetector **76**. Using principles of optical reflectometery, the time domain reflection signals **78** can be converted to distance measurements (by an inverse Fourier transform) indicating a distance along the optical fiber **66** of the various inclusions. Knowing these distances allows determination of slight changes in the locations of the microscopic inclusions within the optical fiber (caused by expansion and contraction of the optical fiber **66** with temperature, for example, by cross correlation between frequency domain reflection signals.

[0045] The changes in the locations of the inclusions can be related to temperatures along the optical fiber **66** through knowledge of the expansion coefficient of the glass of the optical fiber **66** to produce temperature profiles **80***a* and **80***b* describing the temperature at multiple points along the optical fiber **66**, with temperature profiles **80***a* and **80***b* indicating, for example, temperatures obtained while the heater element **54** is deactivated and activated, respectively.

[0046] At each location, the difference between signals **80***a* and **80***b* can be used to produce a measure of thermal resistivity **82** in the material adjacent to the probe **22** at that location with lower temperature differences indicating a higher thermal conductivity material. By applying a threshold **84** to this measure of thermal resistivity **82**, a liquid height **86** may be displayed, for example, on display **46** indicating the location of the surface level **12**.

[0047] Alternatively, it will be appreciated that the heater element **54** may remain activated and a single signal **80** may be acquired providing temperatures that reflect an underlying convection or thermal conductivity at the various points along the optical fiber **66**.

[0048] Referring now momentarily to FIG. **7**, instead of using a fixed threshold as shown in FIG. **4**, the measured thermal resistivity **82**. (reflecting apparent thermal resistance, possibly caused by convection) may be fit to an empirically or theoretically established curve **85** indicating expected apparent thermal resistivity values on either side of a. surface level **87** for known materials (for example air and sodium **14**). By using a curve fitting process, the determined level **87** indicates the surface level **12** and may be based broadly on multiple points of the thermal resistivity **82** thus providing a. more robust and noise resistant level measurement.

[0049] In order to provide high axial resolution, radial thermal conductivity through the probe **22** or convection from the probe should be promoted relative to axial conductivity such as can be provided by using a small diameter probe, for example, less than **10** millimeters in diameter and taking additional steps to reduce the thermal resistance radially compared to the thermal resistance axially for example by using a thin sheath **58** and minimizing separation between the resistive heating element **60** the outer sheath **50** and the optical fiber **66** and/or using non-isotropic conductive potting media **52**, for example having insulating region space axially along the probe **22**.

[0050] Referring now to FIGS. **4** and **5**, in an alternative embodiment, the probe **22** may be employed to measure a flow rate of liquid heat storage material **14** through the accumulator **16**, for example, from the inlet **18** to the outlet **20**. For this purpose, electrically isolated diametric electrodes **100***a* and **100***b* are inserted through the accumulator **16** at a known location along the axis of flow to contact the electrically conductive liquid heat storage material **14**. The electrodes **100** may be connected to a power supply **102** controllable by the computer **34** to promote an intense current flow between the electrodes **100** through the liquid heat storage material **14** for a short period of time to create a heated zone **104**. Flow of the liquid heat storage material **14** causes the heated zone **104** to progress along the length of the probe **22**.

[0051] Alternatively, natural fluctuations in the variation in the temperature of the liquid heat storage material **14** may be measured without heating by the electrodes **100**. These variations may be detected at multiple points along the probe **22** to generate a temperature profile that can be tracked by correlation with later measurements to deduce movement of the liquid heat storage material **14**.

[0052] Referring also to FIG. **6**, in this case, successive pairs of temperature profiles **80***a* and **80***b* may be obtained not associated with activation and deactivation of the heater but simply at different times. These temperature profiles **80** can be analyzed to detect the passage of the heated zone **104** manifested as a pulsed temperature increase **106** in each of the profiles **80**. By timing the passage of the temperature increase **106** between two different locations indicated by the profiles **80**, a velocity signal **108** may be output, for example, on display **46**,

[0053] Referring now to FIG. **8**, the use of an optical fiber **66** allows the probe **22** to navigate curves up to the limit of flexibility of the materials and ability of the optical fiber **66** to retain internal reflection. Typically, curvature radii **90** of as little as one inch in radius or less than five inches in radius may be tolerated with the presently described materials. As a result, the probe **22** may pass in a serpentine path, for example, through a tank **92** holding materials to he characterized.

[0054] Referring to FIG. **10**, the probe **22** may be placed in a conduit **94** to extend generally perpendicular to a flow direction **96** of material within the conduit. The contained heater element of the probe **22** thus allows flow to be measured at multiple points along the length of the probe **22**.

[0055] It will be appreciated that this invention is not limited to the use with liquid sodium and in some embodiments may be used with conventional materials in non-extreme temperatures, for example, for flow measurement or height measurement. In one embodiment, the system may be used to monitor degradation of solid fuel elements within a nuclear reactor by embedding the probe **22** in that. material, It will further be appreciated that the probe **22** need not be straight but can accommodate gentle bends limited only by the light retention ability of the optical fiber **66** and the flexibility of the surrounding protective elements.

[0056] Certain terminology is used herein for purposes of reference only, and thus is not intended to be limiting. For example, terms such as “upper”, “lower”, “above”, and “below” refer to directions in the drawings to which reference is made, Terms such as “front”, “back”, “rear”, “bottom” and “side”, describe the orientation of portions of the component within a consistent but arbitrary frame of reference which is made clear by reference to the text and the associated drawings describing the component under discussion, Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import. Similarly, the terms “first”, “second” and other such numerical terms referring to structures do not imply a sequence or order unless clearly indicated by the context.

[0057] When introducing elements or features of the present disclosure and the exemplary embodiments, the articles “a”, “an”, “the” and “said” are intended to mean that there are one or more of such elements or features. The terms “comprising”, “including” and “having” are intended to be inclusive and mean that there may be additional elements or features other than those specifically noted. It is further to be understood that the method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0058] References to “a microprocessor” and “a processor” or “the microprocessor” and “the processor,” can be understood to include one or more microprocessors that can communicate in a stand-alone and/or a distributed environment(s), and can thus be configured to communicate via wired or wireless communications with other processors, where such one or more processor can be configured to operate on one or more processor-controlled devices that can be similar or different devices. Furthermore, references to memory, unless otherwise specified, can include one or more processor-readable and accessible memory elements and/or components that can be internal to the processor-controlled device, external to the processor-controlled device, and can be accessed via a wired or wireless network.

[0059] It is specifically intended that the present invention not be limited to the embodiments and illustrations contained herein and the claims should be understood to include modified forms of those embodiments including portions of the embodiments and combinations of elements of different embodiments as come within the scope of the following claims, All of the publications described herein, including patents and non-patent publications, are hereby incorporated herein by reference in their entireties.

What we claim is:

1. A sensor system comprising:

an optical fiber;

a heater strip coextending with the optical fiber;

an optical assembly for transmitting light into the optical fiber and detecting light received from the optical fiber; and

an electronic circuit communicating with the optical assembly and the heater strip to:

(a) characterize temperature at multiple points along a length of the optical fiber from the light received from the optical fiber as influenced by heat output from the heater strip; and

(b) determine and output a measure related to a thermal property of a medium surrounding the optical fiber and heater strip.

2. The sensor system of claim **1** further including a thermally conductive shield around the optical fiber.

3. The sensor system of claim **2** wherein the thermally conductive shield provides the heater element.

4. The sensor system of claim **2** wherein the thermally conductive shield is a tube of a material selected from the group consisting of stainless steel and ceramic, the tube filled with a fluid conductive medium positioned between and inner wall of the tube and the optical fiber.

5. The sensor system of claim **4** wherein the conductive medium is of a moisture-free gas and the conductive shield is hermetically sealed.

6. The sensor system of claim **5** wherein the moisture-free gas is helium.

7. The sensor system of claim **4** wherein the conductive medium is a liquid metal.

8. The sensor system of claim **4** wherein the conductive medium is a fluid at room temperature.

9. The sensor system of claim I further including a sheath surrounding the optical fiber and the heater strip including a conductive potting material holding the heater strip and optical fiber in thermal proximity.

10. The sensor system of claim **1** wherein the heater strip is a resistive wire element providing substantially uniform distributed heating along the length of the heater strip.

11. The sensor system of claim **1** wherein the optical assembly is attached to a proximate end of the optical fiber, and a distal end of the optical fiber attaches to a lossy optic segment suppressing reflectance.

12. The sensor system of claim **1** wherein the optical fiber is a glass, single-mode fiber, free of organic cladding material.

13. The sensor system of claim I wherein the optical assembly provides a variable wavelength laser and a photo detector positioned at a distal end of the optical fiber to transmit light into the optical fiber through a beam splitter and receive light out of the optical fiber through the beam splitter.

14. The sensor system of claim **13** wherein the electronic circuit provides a Fourier transform reflectometer characterizing temperature by monitoring Raleigh scattering from inclusions in the optical fiber as modified by a change in temperature of the optical fiber.

15. The sensor system of claim **13** wherein the electronic circuit characterizes locations of Raleigh scatterers within the optical fiber and correlates them to known temperature locations to deduce temperature and determines temperature difference with activation of the heater to determine thermal properties.

16. The sensor system of claim **13** wherein the electronic circuit determines a material interface by fitting a curve to the determined thermal properties, the curve providing example thermal properties expected for particular materials at a material interface.

17. The sensor system of claim **1** further including a tank holding a liquid heat storage material selected from the group consisting of a liquid metal and a liquid salt and wherein the optical fiber of the sensor system extends through a surface boundary of the liquid heat storage material and wherein the output of the electronic circuit provides a liquid level height of the liquid heat storage material.

18. The sensor system of claim **1** wherein the probe is flexible to allow operation with a curvature of the probe having a radius of curvature less than 5 inches.

* * * * *