METHOD AND APPARATUS FOR DETERMINING PROPER CURING OF PIPE LINERS USING DISTRIBUTED TEMPERATURE SENSING

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ABSTRACT

The present invention relates to method and apparatus utilizing distributed temperature sensing (DTS) to monitor the temperature of a cured-in-place pipe liner to determine if proper curing temperatures and times are achieved. More particularly, an optical fiber is placed in the pipe between the original pipe and the liner running the entire length of the liner. The optical fiber is coupled to a DTS unit at one end. During curing of the liner, the DTS unit sends light pulses down the fiber from one end and detects the characteristics and time delay of light backscattered to the unit. The characteristics of the backscattered light is indicative of the temperature of the optical fiber, while the time delay between the sending of the light pulse and the detection of any portion of the backscatter signal is indicative of the round trip time of the light within the fiber, and thus the distance down the fiber from the DTS unit from which that particular backscatter signal originated.
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CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is based on, and claims priority to, U.S. Provisional Application No. 61/473,459, filed Apr. 8, 2011, the entire contents of which are fully incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The invention relates generally to the curing of cured-in-place pipe liners. More specifically, the invention relates to a method and apparatus for assuring that a cure-in-place liner installed in a pipe is fully cured.

BACKGROUND OF THE INVENTION

[0003] It is often necessary to repair pipes, tubes and the like, such as sewer pipes, that are disposed in locations that are difficult or impossible to access. Some such situations are encountered in connection with underground sewers, storm water, potable water, gas, and other utility pipes. As pipes age, they begin to leak or fail structurally and require replacement or repair. Replacing pipes, especially underground, can be extremely difficult and expensive. Accordingly, technologies have been developed to repair pipes in locations that are difficult to access, rather than replace them. One such technology involves the use of cured-in-place pipe liners that can be inserted within old pipes to essentially replace the old pipes. Specifically, cured-in-place pipe liners are known in which a flexible tube (often referred to as a sock or bag) comprising a curable resin disposed on a backing sheet, such as a felt or polymer sheet, is used to line the inner diameter of an old pipe with what will essentially be a new pipe. Cured-in-place pipe liners are very cost effective because it requires little or no digging, i.e., access is necessary only at the upstream and downstream ends of the pipe segment to be lined, which commonly are readily accessible through manholes.

[0004] Cured-in-place linings for sewer pipes, for example, can be installed in segments of very long lengths, reaching several kilometers, if necessary. However, segments of 360-400 feet between manholes are most common.

[0005] Typically, a cured-in-place liner is delivered to the site as a hollow tube with the curable resin on the inside of the tube and the polymer backing on the outside. In some types of cure-in-place lining operations, one end of the sock is closed and the open longitudinal end of the sock is positioned adjacent one end of the pipe segment to be lined. Pressure is then applied to simultaneously exert the sock (so that the resin ends up on the outside and the backing on the inside of the sock) and force the sock into the pipe segment. Other techniques also are known for inserting the liner into the pipe, including, but not limited to pulling the liner with a cable from the downstream end of the pipe segment to be lined, attaching the liner to a pipe crawler that travels down the pipe segment pushing or pulling the liner along with it, and using water tower inversion. When such pushing or pulling techniques are used, the liner does not necessarily need to be closed at one end.

[0006] Then, if necessary, one or both ends of the liner are capped to make it air-tight for pressurization. The liner is then pressurized (e.g., from the open end or through a side valve) to cause it to expand to conform to the inner wall of the original, old pipe as well as simultaneously heated to cause an exothermic reaction to cure the liner, thereby forming a new pipe within the old pipe having almost as large a cross-section as the original pipe. The pressurization and heating can be performed by forcing hot water or steam under pressure inside the liner. The specific pressure and heating profile will, of course, depend on the particular resin composition, but an exemplary profile may require heating to between 125°F and 200°F at a pressure between 3 psi and 15 psi for between 1 and 1.5 hours. The pressure and heat in the pipe is monitored by pressure and temperature gauges to assure that they both stay within prescribed ranges for a sufficient duration to assure that the exothermic reaction occurs fully to properly cure the resin.

[0007] After the resin is properly cured and the liner cools down, any excess liner at one or both ends of the lined pipe segment are cut off to leave an open, newly lined pipe segment.

[0008] The resin must be maintained at a certain minimum temperature and pressure for a certain minimum period of time in order to properly cure the resin. However, there can be significant temperature variations within the liner so that a single temperature gauge does not provide sufficient information to assure that the temperature is within the prescribed range everywhere within the pipe so as to assure proper curing over the entire length of the lining, especially as the lengths of the segment become longer. If the liner is not completely cured over its full length, the entire lining operation may have been for naught.

[0009] Many factors can contribute to temperature variations within the lining, such as poor heating fluid circulation. Another common cause of temperature variation within the pipe segment is because different portions of a pipe segment may pass through different environments with different thermal coefficients. For instance, one portion of a pipe segment may extend under a roadway while another portion runs under a river and yet another portion is above ground and, therefore, exposed to the cold outside air. The portion under the roadway is likely to be hotter than the portions under the river or exposed to the air because the water in the river or the outside air will act as a much more efficient heat sink (especially in cold weather) than the roadway. If the entire length of the liner has not been properly cured, the entire installation may be at risk of failing. Accordingly, it is important to assure to the greatest extent possible that the entire length of the liner has been properly cured.

[0010] Various solutions for monitoring the temperature of the liner at multiple locations along its length have been proposed and/or used, including placing thermocouples at multiple locations in larger pipes and inserting temperature sensing chips at multiple locations in smaller pipes to monitor the temperature at various locations within the pipe. Such solutions are costly, time consuming and/or labor intensive. They also provide temperature information only at discrete locations and distances along the pipe. Yet further, they are relatively bulky components that commonly remain in the pipe after installation and impede the flow of fluid within the pipe.

SUMMARY OF THE INVENTION

[0011] The present invention utilizes distributed temperature sensing (DTS) to monitor the temperature continuously...
over the length of a cured-in-place pipe liner over time to determine if proper curing temperature and time are achieved during cured-in-place pipe lining operations. DTS is a technique involving the sending of optical signals along an optical fiber wherein the characteristics of the light that is backscattered within the fiber is indicative of the temperature of the fiber at the location within the fiber from which the light is backscattered. More particularly, an optical fiber is placed in the pipe between the original pipe and the liner running the entire length of the liner and is coupled to a DTS unit that generates pulses of light sent down the fiber and detects the backscattered light from the fiber. During curing, light pulses are sent down the fiber from one end. The characteristics of any portion of the backscattered light received at a DTS unit indicates the temperature of the optical fiber while the time delay between the sending of the light pulse and the detection of that portion of the backscatter signal is indicative of the round trip time of the light within the fiber, and thus the distance along the fiber from the DTS unit from which that particular backscatter signal portion originated. Hence, the DTS data provides the temperature in the liner continuously over the entire length of the optical fiber. Pulses may be sent down the fiber (and the backscatter signal read) at periodic time intervals to provide temperature information at time intervals of virtually any desired regularity.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a temperature monitoring system in accordance with the principles of the present invention being used in a sewer pipe being lined with a cured-in-place liner.

FIG. 2 is a functional block diagram of a DTS unit in accordance with the principles of the present invention.

FIG. 3 is a diagram of the equipment at one end of a pipe segment being lined in accordance with the principles of the present invention.

FIG. 4 is a diagram of the equipment at the other end of a pipe segment being lined in accordance with the principles of the present invention.

FIG. 5 is a graph showing exemplary information that may be shown on a display of a DTS unit in accordance with the principles of the present invention.

FIG. 6 is a diagram of an exemplary protective case for the connector of the optical fiber cable during transportation along a pipe.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a schematic diagram of a pipe segment in the process of being lined in accordance with the principles of the present invention and showing the various components involved in the practice of the present invention. FIG. 1 shows the process near an end stage so as to illustrate all of the components involved. Particularly, a segment of pipe 101, such as sewer pipe, that is in need to repair is disposed underground and is accessible only at discrete points adjacent manholes 104a, 104b in the street, e.g., commonly spaced apart approximately 360-400 feet in the United States. Accordingly, a 360-400 foot long sock of cured-in-place pipe liner 103 is provided for lining the pipe 101. Before the liner 103 is placed in the pipe 101, an optical fiber cable 105 is placed in the pipe 101. Preferably, the optical fiber cable is longer than the actual pipe segment so as to provide at least approximately ten meters of extra cable at the far end and any extra cable needed at the near end to couple the cable 105 to a Distributed Temperature Sensing (DTS) unit 107 as will be described in more detail below. Particularly, when reading backscatter light data for DTS, it has been found that the light reflected or backscattered from the far end of the fiber (the end remote from the DTS unit 107 that generates the pulse and reads the backscatter light characteristics) is subject to effects that cause it to not reliably reflect the temperature of the fiber. The various effects from the far end of the cable make it difficult or impossible to obtain accurate temperature readings from approximately the last ten meters of the fiber. Accordingly, it is desirable to position at least the last ten meters of the fiber outside of the pipe 101. The cable 105 has a connector 108 on one end for coupling it to the DTS unit 107. Any conventional optical connector form may be used. The other end of the cable requires no special treatment or connection and may be left bare and unpolarized if desired.

Before the liner 103 is placed in the pipe segment 101, the optical cable 105 is placed in the pipe extending from one end to the other plus at least about ten meters sticking out of the pipe at the remote end and enough extra fiber at the near end to allow the fiber to come above ground and be coupled to a mating connector 113 on the DTS unit 107.

The optical cable 105 should be sufficiently durable and rugged for the particular environment in which it is being deployed. It should be capable of withstanding the temperature variations and pressure involved in curing cured-in-place liners and to withstand the wear of being dragged along a pipe for a long distance. It also should be sufficiently impervious to moisture in the environment of the pipe as well as moisture from steam or water pressurization of the liner. Furthermore, a desirable trait of optical cable used for this purpose is the ability of the fiber within the cable 105 to move at least slightly relative to the jacket (e.g., insulation and protective sheath). Particularly, the force placed on the cable 105 during pressurization to cause the liner 103 to conform to the inner wall of the old pipe 101 can cause the cable to stretch, shift, and/or flatten. Hence, it is desirable to use an optical cable that permits the encasement of the cable to do all of those things without damaging the optical fiber within the cable.

In one embodiment, a pipe crawler (not shown) of any of the types well known in the art of underground pipe inspection or maintenance may be adapted to pull the optical cable 105 from the one end 101b to the other end 101a of the pipe segment 101. Preferably, the connector 108 is placed in a protective case for protecting the connector on the end of the cable 105. FIG. 6 shows an exemplary protective case 181 of a clamshell configuration. The case 181 comprises two halves 183, 185 coupled together by a hinge 187. A mating closure mechanism (not shown), such as a mating snap and snap receiver or a mating groove and bead around the edges of the two halves 183, 185, respectively, preferably is provided to allow the case to be easily opened and snapped shut. A small gap 186 may be provided between the edges of the two halves over a short segment of the clamshell halves to allow the cable to exit the case 181 when it is snapped shut. The insides of the two halves 183, 185 are lined with a medium density, closed cellular foam 189 (shown transparent in order not to obscure the other elements in the drawing) that will mold itself around the connector and cable end when the case 181 is shut to protect the connector 108 and keep water and other fluids and dirt from contact with the connector. The halves 183, 185 may be formed of stainless steel or plastic. A hook 184 is provided on the case 181 so that it may be strapped or hoisted to a pipe.
crawler. In the illustrated embodiment, the liner will be forced into the pipe from first manhole 104a and the cable is placed from the second manhole 104b. However, it should be understood that the directions are merely exemplary and that both the pipe and cable can be inserted from either end and can be inserted from the same end or different ends.

[F0022] FIG. 3 is a close up view of the first manhole 104a at a stage after the cable 105 has been run through the pipe segment 101, but before beginning to install the liner 103. With reference to FIG. 3, when the crawler reaches the first end 101a of the pipe segment 101, it is placed through a protective tube 126 that runs from the bottom of the end 101a of the pipe segment 101 up through the manhole 104a. The purpose of the tube 126 is to protect the cable at the eversion station (i.e., the manhole 104a from which the liner will be installed in the pipe segment 101. The cable 105 may be pushed through the tube 126 from the bottom to the top manually by a worker in the manhole. Alternately, a wire (not shown) may be dropped through the tube 126 from the top and attached to the hook 184 of the clamshell case 181 and used to pull the cable 105 through the tube 126. Alternately, the protective case 181 may be removed first and the wire connected directly to the connector 108 for pulling through the tube 126. The tube 126 is rigid and serves the purpose of holding the cable 105 at the bottom of the pipe segment 101 because the eversion process of the liner 103 might otherwise cause the cable 105 to move away from the bottom of the pipe segment 101 and/or may stretch or break the optical fiber. The tube may extend only a short distance near where the liner 103 will curve to enter the pipe segment 101 (where damage is most likely to occur during the liner eversion process), as illustrated in FIG. 1, or may extend all the way up through the manhole opening to further protect the cable 105 from possible damage as it is being up through the manhole, as illustrated in FIG. 3.

[F0023] Next, the clamshell case 181 is opened and the connector 108 is coupled to the mating connector 113 of the DTS unit 107. As previously noted, preferably at least ten meters of cable remains sticking out of the far end 101b of the pipe. The optical cable 105 sits on the bottom of the pipe 101. In this embodiment, only one optical cable is placed in the pipe. Typically, this will be adequate insofar as most insufficient curing instances are a result of insufficient curing along a certain longitudinal segment of the pipe, rather than a radial segment of the pipe. That is, if the liner has reached the proper temperature for the proper amount of time in any given longitudinal point along the liner at the bottom radial portion of the pipe, then it is quite likely that the temperature is substantially similar at the top radial portion of the pipe at the same longitudinal segment. In fact, it is likely that the temperature increases slightly with height within the pipe since heat tends to rise. Thus, it is sometimes advantageous to place the cable at the bottom of the pipe, as illustrated in this exemplary embodiment.

[F0024] However, if the liner is being installed in a pipe for which that assumption is not likely to be accurate, multiple parallel optical cables may be disposed along the length of the pipe at different radial positions around the pipe. For instance four optical cables may be disposed at 90° spacing around the inner wall of the pipe. In such cases, the optical cables may be coated with a sticky substance that will cause them to stick to the side of the pipe since the natural tendency of the cable will be to fall to the lowest point in the pipe. Alternatively, the cable may be placed on an adhesive tape that can be pressed against the wall of the pipe. In yet other embodiments, the one or more optical cables may be fabricated directly into or on the liner. However, depending on the diameter of the pipe being lined typically, the liner may have to undergo a rather tight curve as it is being inverted during installation. Accordingly, it may be necessary to use an optical cable capable of withstanding small radius curvature without breaking. In yet other embodiments, the cable may be installed simultaneously with the installation of the liner, such as by dragging the cable along with the liner.

[F0025] DTS units are well known and will not be described in detail herein. However, FIG. 2 is a block diagram showing the main components of a DTS unit 107. FIG. 2 is merely a functional representation of a typical DTS unit and the individual functional blocks therein are for illustrative purposes only and do not necessarily correspond to different physical components. The unit 107 includes the aforementioned connector 113 for coupling to a mating connector on the end of the optical cable, a light source 115 for generating light pulses coupled into the cable 105 through the mating connectors 108, 113, one or more light detectors 117 for detecting backscattered light from the cable 105, and a microprocessor 121 for processing the backscatter light data to generate information as to temperature and distance data within the pipe. Further, the unit 107 includes means 119 for presenting the temperature and distance data to a user, such as a display, printer, or at least an output port, such as a USB, wireless transmitter, or other computer data port that allows the unit 107 to be coupled to a display or laptop computer for displaying, recording or transmitting the temperature data. The light source may be a semiconductor laser and the light detector may be a photodetector, for example.

[F0026] Referring back to FIG. 1, next, the liner 103 is forced into the pipe segment in accordance with any known or future developed liner eversion process. In this example, two guides 122 are placed at the two ends 101a, 101b of the pipe segment 101, respectively, to guide the liner 103 into the pipe at the eversion end 101a and to guide the liner 103 out and up toward the manhole 104b at the opposite end 101b. The guides 122 are 90° bend guides in this example.

[F0027] With reference to FIG. 4, which is a close up view of the second manhole 104b, in one embodiment, a shoe 140 may be positioned under the guide 122 at the far end 101b of the pipe segment from the eversion unit 110 to even further protect the optical cable 105 and keep it held down at the bottom of the pipe segment. The shoe 140 may be formed of a semi-tubular, fiberglass piece. The outer surface of the shoe, at least at least near its bottom end 143, is lined with a high friction material, such as a closed cellular foam of medium softness, to provide friction for holding the cable in place at the far end 101b of the pipe segment. More particularly, the shoe 126 is forced under the guide 122 between the guide 122 and the cable 105 to even better hold the cable 105 in position at the bottom of the pipe segment 101. Some cured-in-place pipe liner installers do not use guides such as guides 122. In such cases, the use of shoe 126 is highly recommended and will serve the additional function of the guiding the liner up toward the manhole opening. The shoe may be disposed at the end of a telescopic pole 141 so that it may be forced into place from a distance, such as from outside of the manhole. In other embodiments, a tube such as tube 126 shown in FIG. 3 may instead be used at the far end also.

[F0028] As the liner 103 is everted and advanced along the pipe segment 101, the optical cable 105 is being trapped
between the resin-side of the liner 103 (as it is being everted to the outside of the liner) and the bottom of the inner wall of the pipe 101.

[0029] As previously noted, after the liner 103 has been fully inserted into the pipe 101 and everted, with the optical cable 105 trapped between the liner 103 and the inner wall of the pipe 101, the liner 103 is coupled to device 110 for curing the resin. For instance, this is commonly done by capping one end of the liner 103 and coupling the other end to a heat and pressure source 110 that forces a pressurized and heated liquid or gas, such as water or steam, into the liner 103 to cause the liner to expand and press against the inner wall of the pipe and be cured in that position. In some embodiments, the liner may already be coupled to the heating and pressurizing source, since, in some embodiments, the device that inserts and inverts the liner is the same device that heats and pressurizes the liner. In some embodiment, the far end of the liner 103 may already be closed off (and, thus, not require an additional cap).

[0030] While the curing process is being performed, the DTS unit 107 is activated to send light pulses down the fiber and read back the backscattered light data indicative of the temperature of the fiber continuously over its length. The temperature of the fiber, of course, should correlate quite closely to the temperature of the pipe liner in which it is essentially embedded. Software processes and analyzes the data to convert it into time, distance, and temperature data according to well-understood DTS technology principles that will not be described herein in detail. However, briefly described, Distributed Temperature Sensing systems (DTS) are optoelectronic devices that measure temperature by means of optical fibers functioning as linear sensors. Temperatures are measured along the entire length of the optical cable, not at discrete points, but as a continuous profile. Temperatures may be measured with great precision over substantial distances. For example, a typical DTS system can measure the temperature to a spatial resolution of approximately 1 meter with accuracy to within ±1 °C at a resolution of 0.01 °C. Measurement distances of greater than 30 km can be monitored and some specialized systems can provide even tighter spatial resolutions.

[0031] DTS relies on the phenomenon known as the Raman Effect in optical fibers. More specifically, physical conditions, such as temperature, pressure, and tensile forces, can affect glass fibers and locally change the characteristics of light transmission in the fiber. As a result of the damping of the light in the quartz glass fiber through scattering, the location of an external physical effect, such as temperature, pressure or tensile stress can be derived from the characteristics of the backscattered light in the fiber. Thus, the characteristics of the light transmission in the optical fiber can be observed as an indicator of, for instance, temperature. Hence, an optical fiber may be employed as a linear temperature sensor. Optical fibers are commonly formed of doped quartz glass. Quartz glass is a form of silicon dioxide (SiO2) with amorphous solid structure. Thermal effects induce lattice oscillations within the solid. When light falls onto these thermally excited molecular oscillations, an interaction occurs between the light particles (photons) and the electrons of the molecule. Light scattering, also known as Raman scattering, occurs in the optical fiber. The scattered light undergoes a spectral shift relative to the incident light by an amount dependent on the resonance frequency of the lattice oscillation. The light backscattered in the fiber to the input end therefore contains three different spectral shares: namely, the Rayleigh scattering with the wavelength of the laser source used, the Stokes line components from photons shifted to longer wavelength (lower frequency), and the anti-Stokes line components with photons shifted to shorter wavelength (higher frequency) than the Rayleigh scattering.

[0032] The intensity of the anti-Stokes band is temperature-dependent, while the so-called Stokes band is practically independent of temperature. Hence, the local temperature of the optical fiber is derived from the ratio of the anti-Stokes and Stokes light intensities.

[0033] There are two general ways to measure in DTS, namely, Optical Time Domain Reflectometry (OTDR) and Optical Frequency Domain Reflectometry (OFDR).

[0034] The basic principle for OTDR is similar to the round trip delay measurement used for radar. Essentially a narrow laser pulse is sent into a fiber and the backscattered light is detected and analyzed. The time it takes any portion of the backscattered light signal from the pulse to return to the detection unit dictates the distance to the portion of the optical fiber that generated that signal portion. The characteristics of that light are indicative of the temperature at that point in the optical fiber.

[0035] According to the Optical Frequency Domain Reflectometry (OFDR) technique of DTS, the backscattered light signal is detected over a measurement time period as a function of frequency in a complex fashion, and then subjected to Fourier transformation to derive temperature information as a function of distance along the fiber. The essential principles of OFDR technology are the quasi-continuous wave mode employed by the laser and the narrow-band detection of the optical backscatter signal.

[0036] As noted above, DTS systems are presently available on the market that are capable of operating over extremely long distances with a spatial resolution of approximately 1 meter with accuracy to within ±1 °C at a resolution of 0.01 °C and at virtually any temporal resolution. Such resolutions far exceed the reasonably necessary resolutions for the present application. Accordingly, lower-end commercially available DTS devices may be adapted for use in connection with the present invention, thus allowing the construction of DTS units for the present invention that are relatively low-cost; making the present solution very cost-effective. In one embodiment of the invention, the DTS unit 107 has a single optical channel (i.e., it can be used with one optical fiber), a temperature resolution of 1.0 °C and a spatial resolution of 1.3 meters. It is adapted for use with multimode graded index 50/125 μm or 62.5/125 μm optical fibers. Measurements may be taken at any reasonable time intervals. Thus, if cure times are on the order of 1-4 hours, reasonable time intervals for temperature measurements may be 1 to 5 minutes or even greater. Alternately, for smaller liners with quicker cures or just to collect more data, samples may be taken as often as every 10 seconds or less.

[0037] The temperature data may be reported in any reasonable form, such as text, graph, or chart. The software may be designed to provide alerts (e.g., sounds, graphical symbols, etc.) to certain conditions. For instance, an alert may be issued when the temperature detected throughout the entire pipe segment reaches the minimum curing temperature. Also, it may display a running timer showing the duration that the temperature has been continuously above the minimum recommended cure temperatures. Other alerts may be issued if and when, for example, the temperature dips below the mini-
mum required temperature for cure anywhere in the pipe segment, and/or the temperature has remained above the minimum recommended cure temperature for the recommended cure duration individually for each and every length segment of the liner.

FIG. 6 is an exemplary graphical user interface showing one way in which temperature data may be efficiently presented to the user. This presentation includes two separate graphs 150 and 160 that may be shown simultaneously or separately. The first graph 150 simultaneously shows two different types of information. The graph shows position along the pipe segment along the horizontal axis and temperature along the left vertical axis and rate of temperature change along the right vertical axis. Preferably, distance may optionally be position on the horizontal axis may optionally be displayed at the user’s choice as actual distance along the fiber or as a segment number. FIG. 6 illustrates segment numbers. With respect to the first type of information shown in graph 150, each bar 151 represents the current temperature (with reference to the left-hand vertical graph axis) at the corresponding 1 meter long segment of the pipe (with reference to the horizontal graph axis). With respect to the second type of data shown in graph 150, line 153 shows the current rate of temperature change (with reference to the left-hand vertical graph axis) as a function of distance along the pipe (the horizontal graph axis).

The second graph 160 shows temperature (line 161) as defined along the vertical axis at a selected one of the length segments along the pipe as a function of time (as defined along the horizontal axis). In the illustrated embodiment, graph 160 for any length segment can be called up for viewing from graph 150 by clicking on the bar 151 corresponding to particular length segment of the pipe of interest. In one embodiment, the two graphs 150 and 160 are shown simultaneously.

In a preferred embodiment of the invention, the software can display data in a number of additional user-selectable forms. For instance, in another presentation style, a graph may be presented illustrating temperature as a function of time. For instance, a line representing the minimum temperature anywhere in the pipe may be plotted on a graph in which the vertical axis corresponds to time and the horizontal axis represents temperature. A straight vertical line of a different color corresponding to the recommended minimum temperature for curing so that the user can readily confirm that the temperature throughout the entire length of the pipe segment remains above the recommended minimum temperature for the desired duration for cure.

In one embodiment, a commercially available DTS device may be combined with custom software to generate and display data in one or more forms that are particularly useful for pipe lining applications, including one or more of the data display modes discussed immediately above.

Once the liner is installed and cured, the excess optical cable 105 and liner 103 protruding from both ends of the pipe segment 101 are cut off and discarded. The remainder of the cable 105 within the pipe simply becomes part of the installation. The cable is a simple optical fiber cable with no active components or moving parts and, thus, is of negligible expense. Furthermore, underground optical fiber is increasingly being used for communication purposes in CATV (Community Antenna Television) and other telecom systems. Accordingly, the optical fiber may be re-used after the liner is installed either immediately or at a later time as communication cable for a communications system. If and when the optical cable must be routed up through a manhole from the bottom of the pipe, the cable should be routed so as not to interfere with the flow of fluid through the pipe. For instance, the cable may be glued, taped, clamped, or otherwise attached to the bottom and/or side wall of the manhole in order to keep it out of the flow in the manhole.

In some embodiments, it may be desirable to install other cables while installing the optical cable at little or no extra cost. For instance, electrical cable may be installed along with the optical cable, the electrical cable being used for communication or electrical transmission and/or for pipe location purposes. Particularly, it is known technology to locate underground electrical cable by transmitting low-power radio frequency signals on the electrical cable and detecting the radio waves emitted by the underground wire with a portable above-ground radio receiver that can be walked or driven above the cable. Typically, the radio frequency signals are of sufficiently low power that the radio receiver can detect the emitted radio signals only when it is positioned directly above or very close to the underground cable. Hence, one can trace the underground cable by following it with the radio receiver. In some embodiments, the electrical cable may comprise a copper filament or sheath incorporated directly within the insulation or sheath of the optical cable.

The present invention allows the observation of the temperature of a cured-in-place pipe liner over its entire length so that installers can be certain that the entire liner has been properly cured. The present invention will reduce environmental pollution because it will result in fewer leaking or structurally failed utility pipes (sewer, gas, etc.) resulting from improperly cured pipes. It is further environmentally friendly because it will substantially decrease energy usage and installation times for such installations. Particularly, in the past, because it was difficult to be certain when the entire liner had been properly cured, it was standard practice to cure for longer times at higher temperatures in order to better assure that the entire liner had properly cured. However, with the present invention, installers will know through direct observation over its entire length when the entire liner has been properly cured, i.e., above the predetermined minimum temperature for the predetermined minimum period of time and, thus, will no longer need to use excessive temperatures and cure times just to be certain of proper curing in the absence of actual, accurate temperature and time data over the entire length of the liner.

The invention also is superior to previous systems because the optical cable is very narrow in diameter and is disposed outside of the lined pipe, and therefore does not impede flow within the pipe.

Having thus described a few particular embodiments of the invention, various alterations, modifications, and improvements will readily occur to those skilled in the art. Such alterations, modifications, and improvements as are made obvious by this disclosure are intended to be part of this description though not expressly stated herein, and are intended to be within the spirit and scope of the invention. Accordingly, the foregoing description is by way of example only, and not limiting. The invention is limited only as defined in the following claims and equivalents thereof.

What is claimed is:
1. A method of curing a cured-in-place liner within a tube segment, the tube segment having a first longitudinal end, a
second longitudinal end and a length between the first and second longitudinal ends, the method comprising:

placing an optical fiber within the tube segment extending longitudinally from at least the first end to the second end of the tube segment, the optical fiber having a first longitudinal end, a second longitudinal end and a length between the first and second longitudinal ends;

positioning a liner within the tube segment extending longitudinally from the first end to the second end of the tube segment, the liner comprising a curable material for lining the tube;

coupling the first longitudinal end of the optical fiber to a distributed temperature sensing unit;

heating the liner to cure the curable material; and

measuring the temperature of the optical fiber continuously along its length via distributed temperature sensing using the distributed temperature sensing unit.

2. The method of claim 1 wherein the measuring comprises measuring the temperature at periodic time intervals.

3. The method of claim 1 wherein the tube is a sewer, water, or gas pipe.

4. The method of claim 1 wherein the placing occurs prior to the positioning.

5. The method of claim 1 wherein the placing occurs simultaneously with the positioning.

6. The method of claim 5 further comprising the step of attaching the optical fiber to the liner prior to the positioning of the liner within the tube segment.

7. The method of claim 5 further comprising ceasing the heating responsive to measurements taken during the measuring reflecting one or more predetermined conditions.

8. The method of claim 7 wherein the one or more predetermined conditions comprise the entire length of the optical fiber that is within the tube being above a first predetermined temperature for at least a first predetermined period of time.

9. The method of claim 1 wherein the heating further comprises pressurizing the liner.

10. The method of claim 1 wherein the curable material of the liner is disposed on the inside of a tubular backing sheet and wherein the positioning comprises inverting the liner as it is being positioned within the tube so that the curable material is on the outside of the backing sheet at the end of the positioning.

11. The method of claim 1 wherein the placing comprises placing the optical fiber along the bottom of the tube.

12. The method of claim 1 wherein the placing comprises placing a plurality of optical fibers in the tube substantially parallel to each other and substantially evenly radially spaced from each other.

13. The method of claim 1 wherein the placing comprises placing the optical fiber such that the second end of the optical fiber extends at least ten meters beyond the end of the tube segment.

14. The method of claim 1 wherein the measuring comprises:

issuing a light pulse into the optical fiber from the first end of the fiber;

detecting light backscattered from the optical fiber at the first end of the optical fiber; and

calculating the temperature of the optical fiber continuously along its length as a function of one or more characteristics of the backscattered light and the delay time of the backscattered light since issuing the light pulse.

15. The method of claim 1 further comprising:

determining if the temperature of the optical fiber has been within a predetermined temperature range continuously during a predetermined time range.

16. The method of claim 15 further comprising:

measuring the pressure within the tube liner contemporaneously with the measuring of the temperature.

17. A system for curing cured-in-place pipe liner in a pipe segment having a first longitudinal end, a second longitudinal end and a length between the first and second longitudinal ends comprising:

an optical fiber disposed within the pipe segment extending longitudinally from at least the first end to the second end of the tube segment, the optical fiber having a first longitudinal end, a second longitudinal end and a length between the first and second longitudinal ends;

a pipe liner within the tube segment extending longitudinally from the first end to the second end of the tube segment, the liner comprising a curable material for lining the tube;

a distributed temperature sensing unit coupled to the first end of the optical fiber adapted to measure the temperature of the optical fiber continuously along its length via distributed temperature sensing.

18. The system of claim 17 further comprising:

a source of heat and pressure; and

a coupling mechanism for coupling the source of heat and pressure to the liner for heating and pressurizing the liner.

19. The system of claim 18 further comprising a computer program product recorded on computer readable medium comprising computer executable instructions for generating a report of temperature of the fiber as a function of one or more of time and longitudinal position within the fiber.

20. The system of claim 17 wherein the optical fiber is contained within an encasement and wherein the optical fiber is capable of movement relative to the encasement.

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