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Fiber Optic Technology for Heated Sulphur Pipelines
A Dramatic Improvement in Safety and Reliability in Sulphur Transportation

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The increased emphasis on the integrated sulphur pipeline approach along with the bundling of state of the art technologies have significantly improved the safety and reliability of these pipelines. Heated sulphur pipelines have been a constant challenge to the industry because sulphur flows at a relatively high temperature domain within a tight temperature window, often within 25-35 degrees Celsius of its solidification temperature. In addition, elevated temperatures often cause unacceptable movements in the pipeline, unless extreme care is given in piping design and installation methodology. Another important consideration is the re-melting / heat-up of solidified sulphur without structural damage to the pipeline. Increasingly, the protection of the pipeline from third party intrusion and other such hostile activities has also become a major concern.

The most dramatic improvement in the safety and reliability of the heated sulphur pipeline is due to the role played by fiber optic technology. The innovations and advancements in fiber optic *technology have made its mark in many aspects of the heated sulphur pipeline performance. The use of fiber optic distributed temperature sensing (DTS) has become popular in sulphur pipelines during the past 7 years. Today's marketplace increasingly demands the ability to monitor the temperature of the entire length of the pipeline within a tight temperature window. The impact of the technology in the re-melting process has revolutionized the safety and reliability of the heated sulphur pipeline. Fiber optic technology has proven to be a major player in pipeline operational stability, prevention of catastrophic pipeline ruptures, and prevention of potential unwanted third party intrusion. It has also proven to be an effective tool in efficient testing and commissioning of sulphur pipelines.*

INTRODUCTION

Considerable improvements and technology advancements in heat delivery methodology have enhanced the dependability and predictability of pipeline heating systems. Huge advancements in thermal insulation material performance and systems have been a welcome addition that provides better management of heat loss and a stable thermal profile for an entire pipeline. Advancements in electric trace heating systems, especially with skin-effect heat management systems, have proven to be safe and reliable. The introduction of engineered thermally isolated pipe supports and anchors has also immensely improved the pipeline structural integrity. This paper briefly looks into the heat management systems with a particular consideration for skin-effect electric trace heating, a brief reference to thermal insulation systems, engineered piping system components, and the role of fiber optic technology for many facets of sulphur pipeline performance, including the safe re-melting of solidified sulphur. Also included is a reference case study to show the impact of fiber optic technology in actual applications, especially as an important tool in start-up, testing, commissioning, and preventive maintenance of the heated pipeline.

OPTIONS FOR SULPHUR TRANSPORTATION

The new millennium has seen a rapid global focus on the discovery of new energy sources, with an ever growing dependency on heavier crudes. The search for these energy sources has resulted in a number of byproducts, including sulphur, that require special attention in off-site transportation. The world's expanded focus on safety and reliability, and the increased concerns in environmental protection requirements have been a major challenge to energy producers. Transporting liquid sulphur through the use of trucks and rail has been a major and traditional method of transportation. On site sulphur blocking and transportation of these sulphur blocks is also employed in some cases. The use of sulphur granulation plants has become popular with many energy producers. Liquid sulphur is granulated (pelletized) inside the refinery or gas plant and the sulphur granules are transported via rail to distant locations or to seaports for onward transportation to other countries. However, transportation of sulphur by truck or rail has become increasingly unpopular for various reasons. Road accidents and spills have caused the governmental agencies to impose severe penalties and restrictions. All these concerns have pointed towards the use of cross country pipelines to transport sulphur. However, there are many challenges in using these high temperature pipelines for sulphur transportation.

Various technologies and methods are available to provide heat to the sulphur pipelines. Energy producers have used steam, re-circulating fluids (including hot water) and electric trace heating in the past. Steam heating applications have been in use for many years, but mostly for in-plant applications. For cross country applications, steam is often not a practical solution since steam requires additional condensate return lines and other mechanical components that need frequent maintenance. Thus, capital expenditure and operating expenses are relatively high. Hot water based heating systems for sulphur pipelines are another option used in the past. The hot water system is a pipe-in-pipe construction with numerous other special construction features. The main components of a hot water-heated pipeline include sulphur carrier pipe inside a water jacketed pipe, hot water return pipe, and water heaters to heat water over 160°C. This technology, similar to steam based system, has high capital expenditure and high operating/maintenance expenses. Different electric trace heating application methodologies have been deployed in the past to heat sulphur pipelines, including various types of conventional heating cables with relatively short circuit lengths. Other technologies such as impedance heating were occasionally utilized. Even though skin-effect based trace heating systems have existed for more than thirty years, they have increased in popularity over the past 10 to 15 years. Numerous innovations and installation methodologies have made the skin-effect based heat management systems safe and reliable compared to other heating methods.

ADVANCEMENTS IN ELECTRICAL HEATING SYSTEMS FOR SULPHUR PIPELINES

Electrical trace heating technology has been used for various types of pipeline heating applications for over 50 years. The heating applications are primarily for temperature maintenance and to re-melt solidified sulphur. As sulphur operates at a high thermal domain, the choices of conventional cable-based heating systems are relatively few.

Electric trace heating has become popular since the 1970’s and several technologies are commonly used today for pipeline heating (1) (2). They include self-regulating and variable power density cables which are flexible cables that have a Positive Temperature Coefficient (PTC); flexible series-resistance cables, also known as flexible series constant-wattage cables; mineral insulated cables (also constant-wattage heaters) normally used for very high temperature applications; impedance heating systems which use the carrier pipe as the heater as a low AC voltage is applied to it to generate I^2R heating; and skin-effect trace heating systems which use an insulated conductor inside a ferromagnetic heat tube to generate heat.

An increased awareness of safety and reliability in heating cable manufacturing has led to more dependable heating cables for sulphur pipeline applications. However, most of the trace heating cables have limitations in circuit length, electrical power distribution challenges, or complex control and instrumentation requirements. Almost all of these trace heating cables are not suitable for sulphur transfer lines, off site pipelines and long cross country sulphur lines due to the limitations in circuit lengths. In addition, the advent of pre-insulated/pre-fabricated sulphur pipelines has greatly diminished the attractiveness of conventional trace heating cables while making skin-effect systems ideal for long pipeline applications. Skin-effect heating systems have been used in conjunction with fiber optic temperature monitoring systems and pre-insulated pipes on sulphur pipeline heating applications (3).

THERMAL INSULATION MATERIALS AND SYSTEMS

External thermal insulation is an important component of a heated sulphur pipeline. Thermal insulation is applied to provide adequate heat preservation and personnel protection for the above ground sulphur pipelines. Even though a variety of thermal insulation materials have been applied to the heated sulphur pipelines over time, there are recent developments in materials and systems. Common insulation materials used today are mineral wool fiber, expanded perlite, fiberglass, polyisocyanurate (high temperature foam), silica aerogel (nanogel technology), Hitlin™ and calcium silicate. Composite insulation systems, which take advantage of the material properties and cost savings of different thermal insulation materials, are a good option for heated sulphur pipelines. These composite insulation systems are characterized by an inner layer that uses expanded perlite, Hitlin™ or high density mineral wool fiber, an outer layer that uses high temperature polyurethane foam, a high-density polyethylene (HDPE) jacket to prevent moisture ingression, provide UV protection and to function as a weather barrier, and an outer sheet metal (aluminum or galvanized steel) jacket for mechanical protection.

PIPELINE SENSING TECHNOLOGIES

Temperature control for electric trace heating is accomplished through the use of different sensing technologies. Traditional sensors include mechanical devices such as thermostats which employ bimetal or fluid-filled systems to switch the control contacts based on sensed temperature changes. They also include electronic sensors such as thermocouples, thermistors and resistance temperature detectors (RTD). Thermocouples provide a millivolt signal that is proportional to a temperature value. Thermistors are temperature dependent resistors made of semiconductor materials. RTDs sensors are also temperature dependent resistors that change resistance as a function of temperature changes. All of these devices are referred to as point-sensing devices as they can only sense temperature at the discrete location where they are installed. As a result, when these sensors are used for electric trace heating control, they are normally located near one of the ends (and sometimes both) of the heated pipeline. In contrast, fiber optic temperature sensing can be distributed in nature, that is, complete temperature sensing for the entire pipeline can be provided when fiber optic Distributed Temperature Sensing (DTS) is used.

MODELING

Software modeling tools such as Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), and 3D modeling are providing major insights into the details and complexity of trace heating applications. FEA and/or CFD analyses provide various temperature gradients of the pipe and its contents, allowing the designer to select a proper design that meets temperature gradient tolerances required by the application. This is especially true in applications with tight temperature control like molten sulphur. Transient thermal FEA and CFD analyses are now also commonly used to model solidified sulphur re-melt scenarios. Each analysis result can be reported in the form of an animated temperature contour plot of the pipe cross-section. Time vs. temperature graphs can also be presented along with predicting the time required to achieve the specified end temperature during heat-up or cool-down.

FIBER OPTIC TECHNOLOGY FOR HEATED SULPHUR PIPELINES

Fiber optic cables are ideal for transmitting telecommunication data, but are equally effective for detecting changes in temperature, pipeline strain, and unwanted third party interference because of fiber optic technology’s unsurpassed levels of sensitivity, long distance measurement capabilities and electromagnetic immunity. These benefits have led to unique solutions for critical detection and localization and asset performance monitoring. The technologies include Distributed Temperature Sensing (DTS), Fiber Bragg Grating (FBG), Distributed Temperature and Strain Sensing (DTSS), and Distributed Acoustic Sensing (DAS). Fiber optic monitoring systems can continuously monitor the entire pipeline to within one or two meters spatially, registering small variations in temperature, strain, pipe movement and leak detection. By identifying critical problems within minutes, companies can avoid the many negative consequences associated with sulphur pipeline failures.

While Distributed Temperature Sensing (DTS) has been popular in the last few years, strain monitoring is relatively new. A distributed strain sensing system can play a significant role in preventing pipeline mechanical failures by providing accurate information on pipeline movements caused by high pipeline temperatures.

Distributed Temperature Sensing

A Distributed Temperature Sensing (DTS) system uses a fiber optic cable as a sensing element to measure temperature. A laser is used to send pulses of light into the cable. As each laser pulse passes through the optical fiber it generates light known as backscatter that travels back through the fiber towards the source. The intensity of this backscattered light is proportional to the temperature of the cable at the point at which it was generated. Since the velocity of light propagation in the optical fiber is well known, by using an Optical Time-Domain Reflectomer (OTDR) to measure the time between when the pulse was launched and when the backscattered light was detected, the system can determine the exact location in the fiber optic cable where the backscatter was generated. By combining these two pieces of information the DTS can measure the temperature for every point along the fiber optic cable. Figure 1 shows a typical DTS system used for pipeline temperature monitoring.

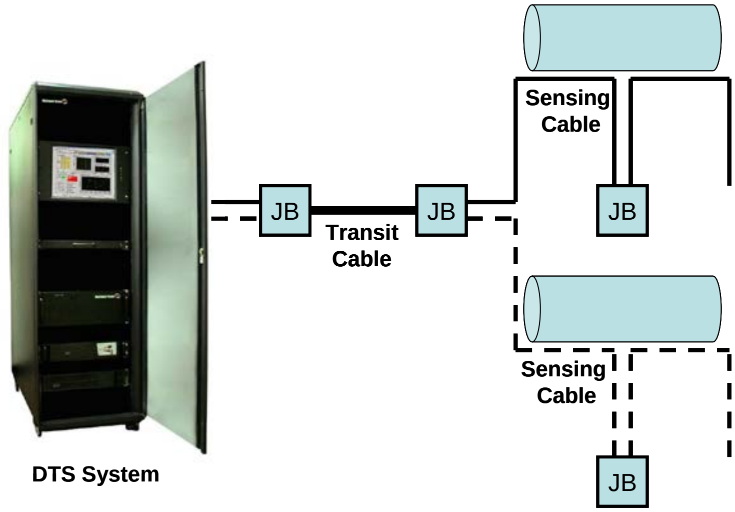

Figure 1. Fiber Optic DTS system configuration.

The DTS produces profiles of temperature versus distance for the entire length of the fiber to which is connected. In addition to temperature profiles, the temperature data can be divided into regions of interest known as zones. Alarm thresholds can also be defined for zones to enable unusual temperature events to be communicated to operators or other systems. Of particular importance will be the role this system plays during sulphur re-melt or heat up conditions. In this case, the DTS system can aid Operations with determining how the pipeline is being heated and what specific zones may be warming or cooling outside the desired temperature range. Figure 2 shows a typical graphic user interface (GUI) display for a DTS system used in a sulphur pipeline heating application.

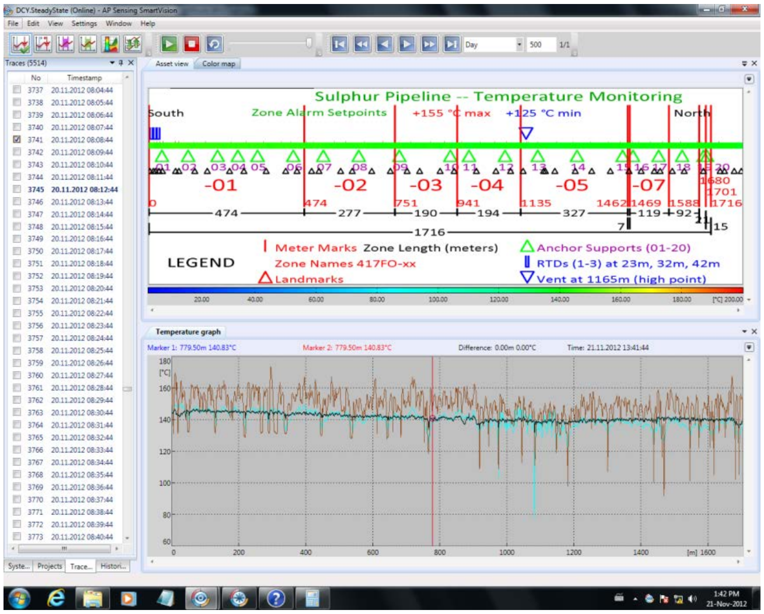

Figure 2. Fiber Optic DTS graphics display.

ENHANCED SAFETY AND RELIABILITY WITH FIBER OPTIC TECHNOLOGY

Sulphur Pipeline Start Up and Commissioning

For the last 7 years fiber optic Distributed Temperature Sensing (DTS) has been successfully used in conjunction with skin-effect trace heating systems to monitor the temperature of entire sulphur pipelines during start-up, commissioning, normal operation, and re-melt.

Heated sulphur pipeline start-up procedures rely on the DTS system to ensure that the empty pipeline is not overheated during a controlled heat up prior to the introduction of molten sulphur. It is possible that temperature excursions at certain locations along the pipeline can exceed the ratings of the pipe's thermal insulation and/or of the skin-effect insulated conductor and may not be detected by the "point temperature sensors" used for heating control. The fiber optic temperature monitoring system provides this information. Locations along the pipeline which can exhibit a relative higher heat loss than the main pipeline (e.g., pipe anchor supports), may also lag behind in the heat up process. These excursions sometimes require that the heat up be performed at a deliberate pace where the heating system is allowed to cycle on-and-off until the entire pipeline temperature stabilizes and there is no risk of over-heating or under-heating.

Once the entire empty pipeline is heated to within the normal operating temperature range of sulphur, sulphur can be safely introduced into the pipeline. The DTS system is also continuously monitored during this stage. As the flowing sulphur travels through the pipeline, its heat capacity stabilizes the temperature of the pipeline and the temperature profile becomes very uniform. However, if sulphur flow is very low, there can be excessive heat loss, resulting in solidification of sulphur. It is only through the use of the DTS temperature monitoring system that operators can see drops in temperature as sulphur flows along the pipeline. Potential localized high heat loss areas (e.g., anchors) and high heat gain areas (e.g., air pockets) can also be identified and corrective measures instituted.

Sulphur Re-melt Challenges

Although the DTS system is extremely helpful during the heat up of the empty pipeline and during sulphur introduction, it is the re-melt of solidified sulphur what makes this fiber optic DTS temperature monitoring system much more valuable.

Under abnormal conditions of a total prolonged power failure, the power supply to the skin-effect trace heating system could be completely cut off. The duration of the power outage may be long enough to result in sulphur solidification inside the pipeline. The properties of sulphur indicate that the solidification process starts below 120°C. Liquid sulphur shrinks (as illustrated in Figure 3) as it changes from liquid to solid. This reduction in volume creates voids at various locations and packed sulphur in other locations. The re-melt process could compromise the pipeline integrity by having hot spots (overheating) at these voids, especially at elevation changes and expansion loops among other random locations; by excessive pressure generated by melting sulphur (expansion) and/or hydraulic shock (release of a slug of solid sulphur) that could potentially burst the pipeline; and by premature pumping of sulphur that contains chunks of solid sulphur that can cause pipeline rupture.

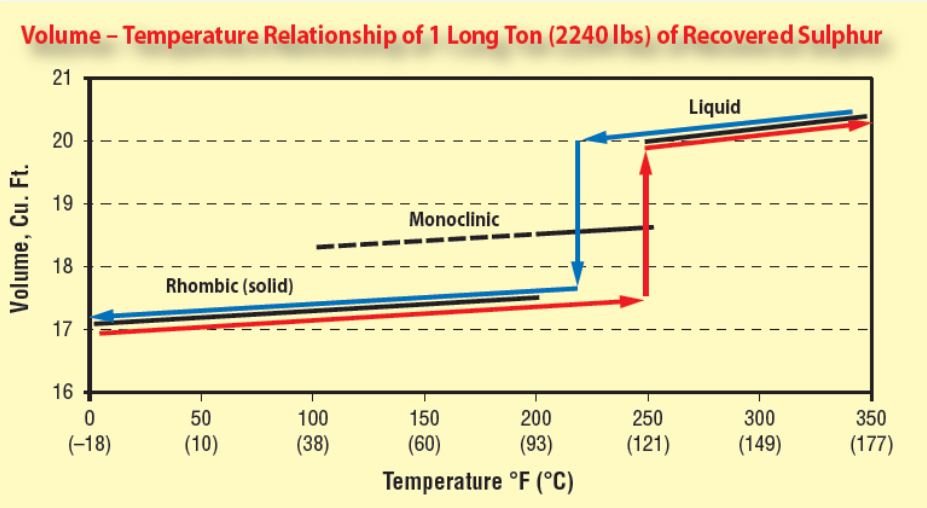

Figure 3. Sulphur volume versus temperature relationship.

Safe and reliable sulphur re-melt programs and procedures have been developed by combining transient FEA and CFD analysis to closely model the characteristic curve of sulphur heat-up and the temperature profile during re-melt and to predict re-melt times. Fiber optic DTS is used to continuously monitor the real-time temperature profile of the pipeline across its entire length to assist Operations and ensure the safe and reliable performance of the skin-effect trace heating system during the sulphur re-melt process. Figures 4 shows an FEA heat up curve at various places of a sulphur-filled pipeline cross-section. Figure 5 shows the dynamic DTS heat up temperature profile plots during a re-melt test.

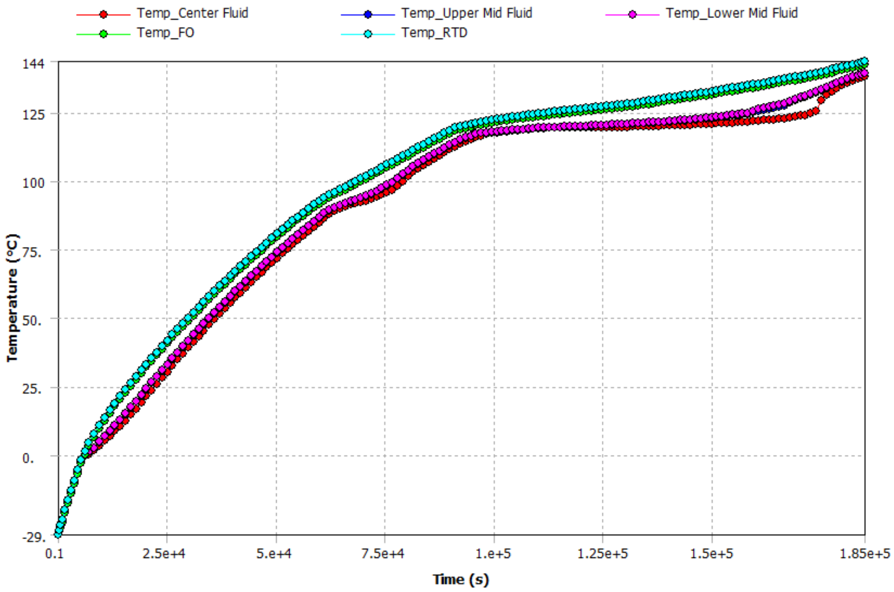

Figure 4. Heat-up curves for 100% sulphur-filled section of a 6” pipeline.

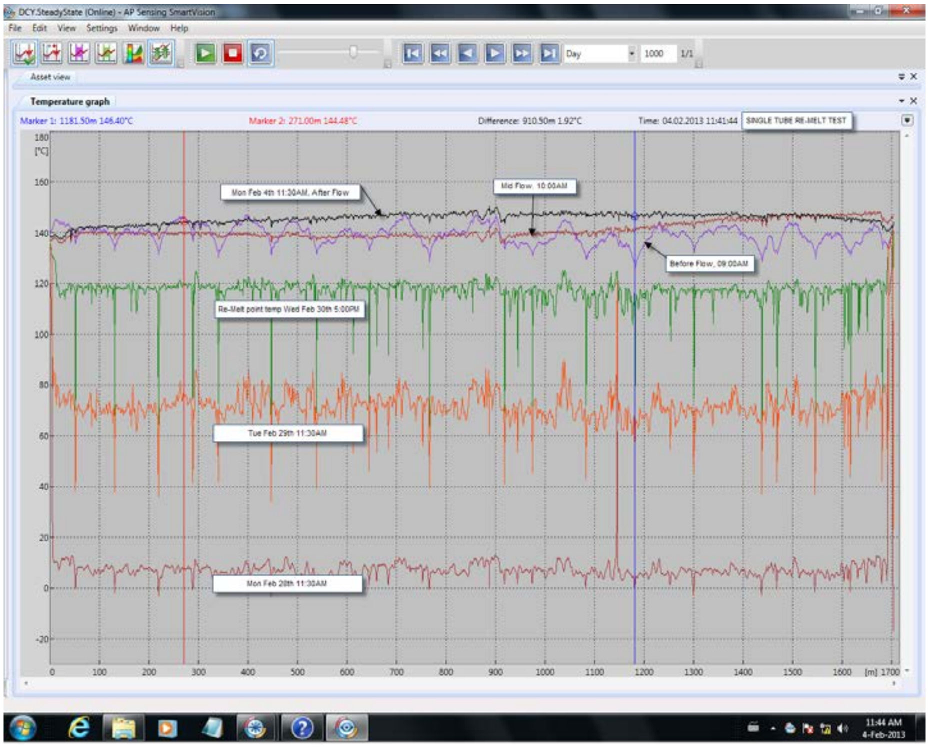

Figure 5. DTS Temperature profiles during re-melt test of a 6" pipeline.

Trouble Shooting and Preventive Maintenance

DTS systems provide "thermal intelligence" by monitoring the temperature of the entire pipeline. They provide an ability to detect any failures of the skin-effect trace heating and thermal insulation systems early enough to allow corrective action. Even though they are mainly used during normal and re-melt operations, they too can be very effective in assisting maintenance personnel during trouble-shooting and preventive maintenance.

DTS systems have been successfully used to accurately locate sections of a pipeline where the thermal insulation system was damaged, improperly installed or compromised. Figure 6 shows the temperature profile of an empty sulphur pipeline that exhibited higher than normal temperature differences during empty pipeline heat up. The pipeline was pre-insulated at the factory and only the field joints and expansion loops were insulated in the field. Detailed review of this profile indicated that the temperature drops were taking place precisely at the locations that were thermally insulated in the field. After further investigation it was determined that some of the field insulation had not been properly installed. Corrective measures were implemented at these locations. Figure 7 shows temperature profile after remediation work was completed for the same portion of the pipeline. Empty pipelines exhibit a degree of temperature variance.

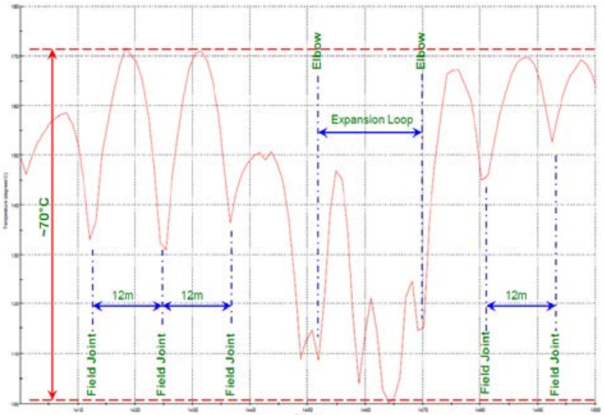

Figure 6. DTS Temperature profile used to locate problematic areas.

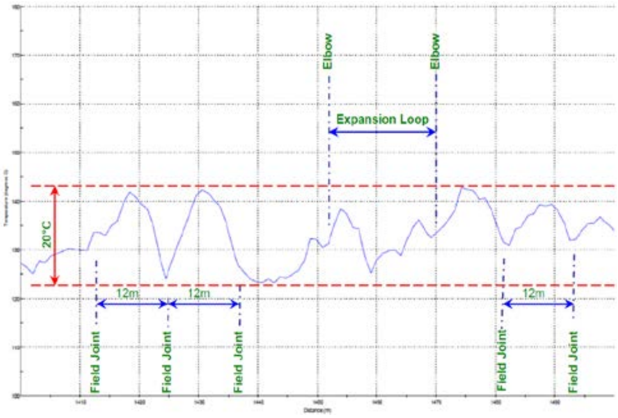

Figure 7. DTS Temperature profile after field insulation fixes.

A SULPHUR PROJECT CASE STUDY

When examining the options for a new 1730m Sulphur transfer line at the Shell Scotford Upgrader in Fort Saskatchewan, Alberta, Canada, numerous trace heating technologies were evaluated (see Figure 8). The solution selected was a completely redundant dual tube skin-effect trace heating system, with fiber optic temperature monitoring. While both tubes are used under normal operation, each tube was designed to have sufficient output power to independently re-melt the entire Sulphur line under typical design winter conditions. With this level of redundancy, maintenance activities could also be performed on the upstream electrical distribution system without affecting the operation of the line.

Figure 8. Shell Scotford facility in Alberta, Canada.

The line was commissioned during the winter from January to February 2013. Average ambient temperatures varied between -27°C to +5°C during the testing. As part of the commissioning procedure of the line, the following steps were performed (see figures 9 and 10):

1. Electrical testing prior to energization
2. Empty pipe heat up to 160°C
3. Pumped liquid Sulphur until temperatures stabilized
4. Blocked in valves and solidified Sulphur in the line
5. Single tube re-melt test
6. Pumped liquid Sulphur until temperatures stabilized
7. Blocked in valves and solidified Sulphur in the line
8. Dual tube re-melt test

In order to heat up the line both tubes were energized in the low power settings. The temperature profile was continuously monitored to ensure that the hottest temperature point did not exceed 160°C. All cold spots were identified via the fiber optic DTS system and resolved prior to proceeding any further. The 0.5m resolution allowed for quick field location of the issues when compared to known landmarks on the graphic display.

After the empty pipe temperature profile was accepted, Sulphur was pumped through the line for an hour. This allowed the temperatures to stabilize on the monitoring system. Once completed, the valves at each end were closed, trapping the liquid Sulphur in the line. Both skin-effect trace heating circuits were then turned off and the line was allowed to cool. It took three days for the temperature to drop below 20°C.

As with the empty pipe heat up, the fiber optic monitoring system was monitored closely during the re-melt procedure. Hot and cold spots were watched closely and the temperature profile was used to manually control the duty cycle of the heat trace controllers. Due to the 0.5m resolution it was also possible to watch the individual Sulphur plugs at each anchor location melt well after other points in the line. Once flow was established the process was repeated for the single tube test.

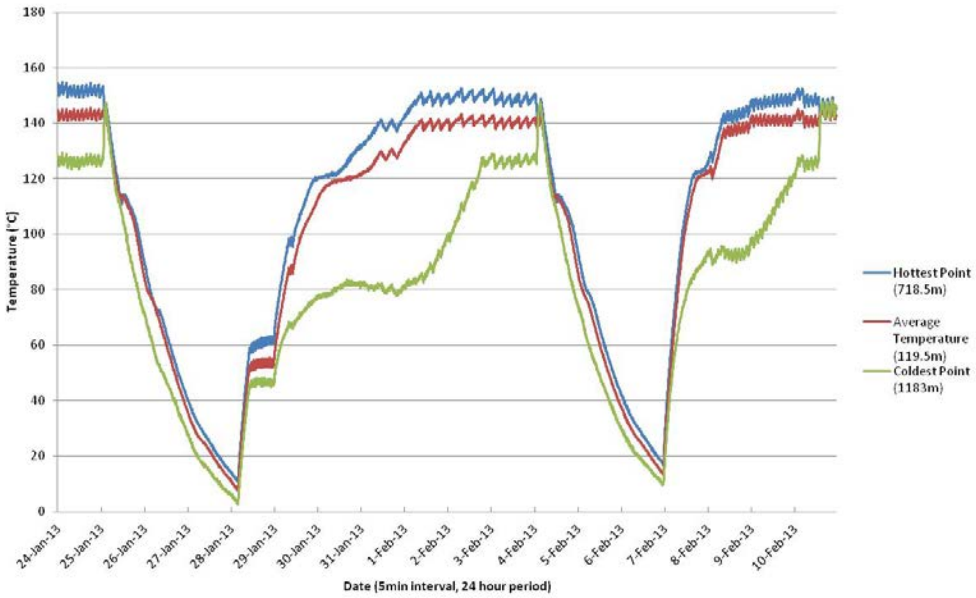

Figure 9. Min, max and average fiber optic temperature for 6" sulphur pipeline during re-melt test.

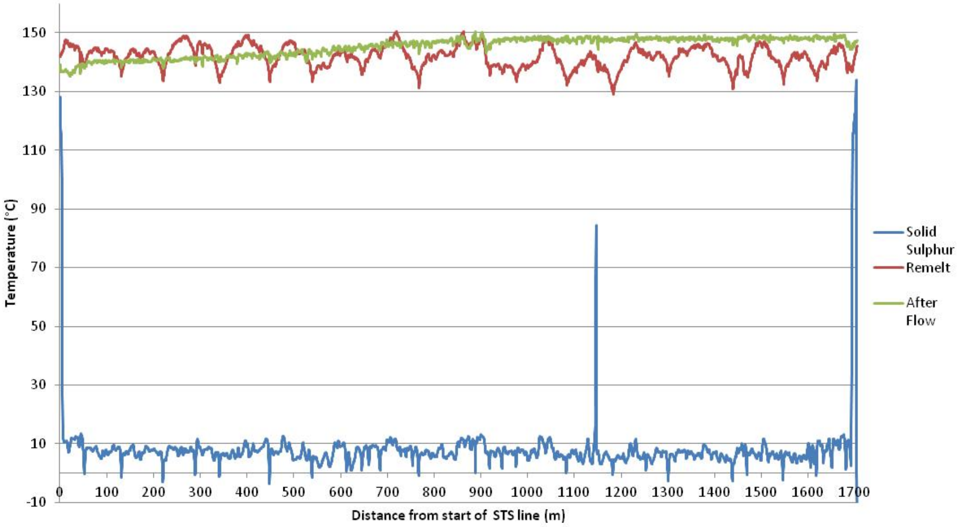

Figure 10. DTS temperature profile for 6” sulphur pipeline during re-melt test.

After the commissioning was completed, the new line was placed into service. The fiber optic temperature monitoring system continues to be used as a monitoring tool and the pipeline continues to operate trouble-free.

CONCLUSIONS

The introduction of the fiber optic temperature monitoring technology has dramatically improved the performance of heated liquid sulphur pipelines around the world. The use of fiber optic based distributed temperature sensing systems has paved the way for highly safe and reliable re-melting programs. Advancements in electrical trace heating technology, especially the use of skin-effect systems, have resulted in efficient heat management solutions for sulphur pipelines. An increased popularity of pre-insulated piping systems and improvements/innovations in thermal insulation materials has had a positive impact in pipeline heat loss management. The emergence of engineered piping installation components such as engineered anchors and various types of engineered pipe supports have greatly contributed to a homogenous heat loss for the entire heated pipeline. The innovative concept of integrated technologies in sulphur pipeline heat management system applications has resulted in dramatic improvements in the reliability and safety by offering real-time thermal intelligence for the critical sulphur transportation market.

References

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