Proceedings of the Thirty-third (2023) International Ocean and Polar Engineering Conference **www.isope.org**
Ottawa, Canada, June 19-23, 2023

ISBN 978-1-880653-80-7; ISSN 1098-6189

Trace heating of wet insulated subsea flowlines

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ABSTRACT

This article evaluates flow assurance by heat trace cables for wet insulated flowlines as an alternative to direct electrical heating or chemicals. Heat trace cables are attractive for their simple and flexible design and that they can be retrofitted. Case studies of a 14" flowline, where trace heat cables are placed outside the coating, indicate that fluid temperatures can be maintained at 25-55 °C. Heating capability depend on flowline geometry, heating cable type and burial depth. Commercial heat trace cables are available for flowline lengths including at least 50 km. Heat trace cables with conventional electrical insulation can deliver power in the 100 kW/km range.

KEY WORDS: Hydrate management; flow assurance; electrical heating; flowlines, trace heating; direct electrical heating.

INTRODUCTION

Electrical heating is used to maintain the mixture of oil, gas and other substances in onshore and subsea flowlines at elevated temperatures to prevent wax and hydrates from causing blockage in the flowline. By heating the flowline electrically, the need for chemical injection is reduced considerably.

Electrical heating has proved to be suitable for short, as well as for long flowlines since heat can be generated evenly along the whole length. Electrical heating is expected to be increasingly deployed as an elegant technical solution to optimize flow assurance management during the service life of production flowline. The electrical heating may be used continuously, at production stops and/or during tail production.

Electrical heating has been used for several decades on onshore facility pipes, probably starting with the simple design of an insulated wire (Burpee, 1977). Later, other techniques emerged, such as induction heating, impedance heating and skin effect heating, (Rafferty, 2002). The latter has been installed on a 600 km line (Hamill, 2016), but it has also been tested on a submerged flowline (Wan, 2020). For subsea pipe-in-pipe installations, heat trace cables exist in a few installations and are described in several publications, e.g., in (Gooris 2016; Verdeil, 2019).

For subsea wet insulated flowlines, direct electrical heating (DEH) is the most used technology and is described in (Nysveen, 2007). DEH has been installed on about 50 wet insulated flowlines since year 2000, (Lervik, 2018), with some of the first installations still in operation. Other heating concepts that exist, but to the authors knowledge have not been installed, are induction heating, (Ahlen, 1992), and trace heated blankets (Marret, 2016). A concept for electrical trace heating of wet insulated flowlines is provided on a web page (Salamander, 2023), but no reference has been found in literature. The same company also provides solutions for downhole heating (Karanikas, 2020).

Trace heating can be very attractive for wet insulated flowlines that will or can be buried (either in soil or by insulated mattresses) and where the fluid temperature requirement is moderate. Trace heating is less complicated than for example DEH and skin effect heating in several ways. There is no need for connections to or modifications of the flowline itself and there is minimal electromagnetic interaction between the trace heating cable and the pipe, or other adjacent structures. This reduces the risk for AC corrosion and the need for anodes. Trace heating can, because of its simple way of operation, be especially attractive where there is a need to retrofit electrical heating. The service time of some existing fields can be extended by retrofitting electrical heating to the flowline.

The aim of the presented work is to investigate whether heat trace cables are feasible for wet insulated flowlines. A simple design is considered, where the cables are placed next to the flowline, i.e. outside the flowline coating. The paper discusses a few relevant case studies. The focus is on the thermal and electrical performances the heat trace design, such as heating capability, cable size, power consumption and efficiency. For comparison, the power consumption of DEH is provided for the same cases. An overview of various heat trace cable types is also provided.

HEAT TRACE CABLES

In heat trace cables, all heat is developed in the cable itself. Thus, heat transfer to the flowline is by thermal conduction. This differs from direct electrical heating where a large share of the heat developed is in the pipe wall.

The heat trace cables can be designed in several ways and can to a large degree be optimized based on project specific needs. Figure 1 shows examples of different designs. The main components of each cable are metallic conductors, electrical insulation, and mechanical protection.

The cables can for example be three-phase with or without mechanical armor. These are off-the-shelf products, offered by multiple cable vendors. A metallic screen will typically be placed around the insulation for electrical safety, to drain capacitive currents and as water barrier. At the far end of the cable, the conductors are short-circuited and the voltage will be close to zero at this end.

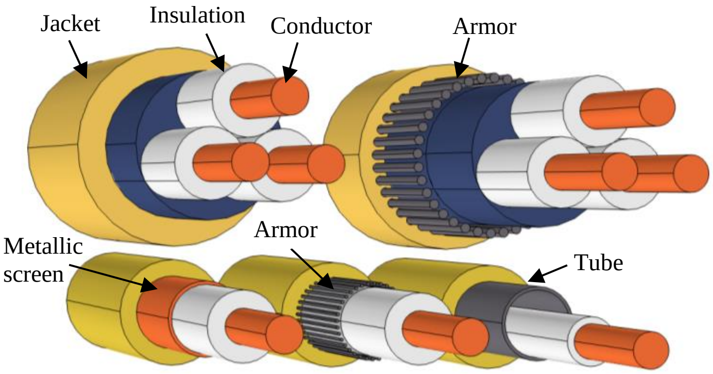

Figure 1: Generic designs of heat trace cables.

The heating cables can also be designed as single-phase for example with a coaxial or dual core design. In the coaxial design, the forward current is conducted by the center conductor, whereas the current returns in a circumferential conductor of for example copper strands, armor wires, or a tube. The latter design is sometimes referred to as "skin effect heating", as most of the heat is developed in the outer tube. There may (depending on system design) be a voltage to ground on the return conductor. In these cases, the jacket must be electrically insulated. The dual core design (not illustrated) is similar to the three-phase design, but with one cable removed. Even though a wet insulated flowline is considered in this article, the heating cable designs could be used in many other applications, such as in flowline bundles or integrated power umbilicals.

For comparison, the piggyback cable used in DEH, see Figure 2, normally consists of a conductor, electrical insulation, and jacket. A large conductor cross-section increases efficiency (less losses in the cable) but increases procurement costs and installation complexity. Depending on installation depth and other installation aspects, mechanical reinforcement may be required. Parts of the conductor can be replaced by steel to increase mechanical performance. The piggyback cable normally has no metallic components except for the conductor, as these will reduce efficiency.

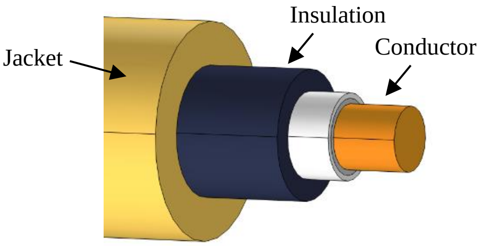

Figure 2: Generic designs of piggyback cable.

The thermal limit of the insulation (cross linked polyethylene, XLPE) used in power cables onshore and offshore is normally 90 °C. Insulation for higher temperatures exists, such as the 120 °C fluorinated ethylene propylene (FEP) used in pipe-in-pipe installations. There exists a variety of insulation types that accept even higher temperatures, but they are typically limited to operate at a few kilovolts. In contrast, XLPE insulated cables are field proven at several hundred kilovolts.

INSTALLATION

Installation of the heating cables and installation tolerances are the main challenges of the trace heating cables concept. In onshore installations, or in very shallow waters, installation can be done with high degree of accuracy. As water depth increases, so does complexity of installation.

For new installations, the heat trace cable should be strapped (piggybacked) to the flowline to ensure proximity for optimal heating. For retrofit installations, the power cable could either be placed on pre-mounted cradles/supports that are fitted to the flowline or laid close to the flowline by manual operation, such as by a remotely operated underwater vehicle (ROV). Manual operation is feasible, but time consuming. Cradles are field proven for positioning piggyback cable in DEH installations after repair of the cable. After installation, the pipe and the cable can be trenched, mattresses can be installed or rocks can be dumped to yield the thermal conditions necessary for the heat trace cables to sufficiently heat the flowline content.

The heat trace cable(s) and the flowline must be embedded in soil or covered by for example mattresses or rock dump. Heat trace cables are not feasible for flowlines that are directly exposed to free-flowing seawater, due to the excessive dissipation of heat to the environment. It is evident that the efficiency and heating capability would increase if the cables were placed inside the coating, like in some skin effect heating concepts. However, this introduces production and installation challenges and is not further pursued in this work.

The idea with mattresses is to thermally insulate the cable-pipe system to prevent heat from escaping. Regular concrete mattresses are in most situations not suitable as they have limited insulation properties. An alternative is bitumen mattresses that have better thermal properties. Standard mattresses are 6 m x 3m and installed one-by-one using an installation frame. One could envisage that they could be made longer but still there will be a joint between each mattress where heat will escape. It is very difficult, time consuming and expensive to get each mattress square on to the next, so inevitably there will be gaps. Another thing is to avoid water circulation in the channel under the mattress. A reelable mattress solution may be the only method to ensure some form of controlled insulation around the pipe, as described in (Marret, 2016).

A challenge is to contain the heat on the flowline. To allow this, the operator must allow the soil as part of the insulation system in design. The thermal property of the soil then becomes one of the most important values for heat trace design. Generic values can be used, but will have limited accuracy if the mineral composition, compaction and density/degree of porosity is unknown and may change over time. To calculate or measure a representative thermal conductivity is therefore not straightforward.

Post-lay burial of pipelines is common and is the method normally used. It could be possible to install the flowline before installing the cable. However, it would be very difficult or impossible to guarantee that the cable is close enough to the flowline in a trench, this both due to the wide disparity in trench geometry one can end up with, and the risk of trench wall collapse and soil on top of the pipe before installing the cable.

If the cable is installed prior to burial, then one needs to make sure it is strapped to the pipeline or otherwise lose control of where it ends up. Burial by jetting in this case is the only option, as using a plough results in a high likelihood of damaging the cable. When jetting one first make a run to lower the pipeline to say 1-1.5m, then a second under-reaming run is made to collapse the trench walls to give burial. It will not be possible to guarantee any kind of minimum burial depth, hence one needs to plan for post-lay sand dumping for insulation that later needs to be stabilized by rock. Not all soils are suitable for trenching, and also some soils are more suitable for ploughing than jetting.

SYSTEM DESCRIPTION OF CASE STUDIES

Electrical and thermal analysis are performed for a 14-inch wet insulated flowline. The flowline is installed at three different locations:

i) at the seabed and covered by mattrasses (Figure 3-Figure 4),
ii) buried to top (Figure 5) and
iii) buried 1 m (Figure 6).

The cables are placed next to the flowline (about 5 o'clock) and outside the coating. A three-phase heat trace cable is considered in the calculations, but heat requirements will be similar also for single-phase cables. The DEH system is a regular single-phase type.

The calculations are performed in the tool COMSOL Multiphysics using the heat transfer and magnetic fields physics modules in steady state conditions. Convection in the fluid content and trapped water below mattresses is included by increasing the thermal conductivity compared to stationary fluids. See Table 1 for flowline design data, Table 2 for thermal and electrical conductivity and Table 3 for other design data. The piggyback cable conductor is 240 mm^2 with outer diameter of 88 mm.

The following individual parameter sensitivity studies are considered:

- Coating thickness: 1 mm (55 mm is base case).
- Thermal limit of cable insulation: 120 °C (90 °C is base case).
- Two heat trace cables (one is base case).

Table 1: Flowline design data.

Element	Outer diameter	
	1 mm coating	55 mm coating
Fluid	304.8	304.8
Flowline steel (25.4 mm)	355.6	355.6
Coating (1 and 55 mm)	357.6	465.6

Table 2: Thermal (k) and electrical (σ) conductivity.

Element	k [W/(mK)]	σ [S/m] @ 20 °C
Cable conductor	385	$5.5 \cdot 10^7$
Cable insulation & fillers	0.287	-
Flowline content	3	-
Flowline steel	40	$4.5 \cdot 10^6$
Flowline coating	0.18	-
Soil	1.5	1
Trapped water	3	3.3
Mattress	0.3	-

Table 3: Other design data.

Element	Value
Ambient water temperature	6 °C
U-value 55 mm coating (ref ID/OD)	4.4 / 3.8 W/(m^{2}K)
U-value 1 mm coating (ref ID/OD)	211 / 181 W/(m^{2}K)
Relative magnetic permeability (steel)	400
Thermal limit of cable insulation	90 and 120 °C
Mattresses thickness and width	15 cm / 2 m
Power frequency	50 Hz

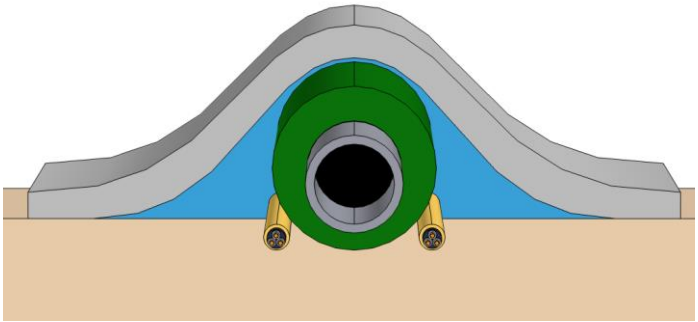

Figure 3: Heat tracing covered by mattresses.

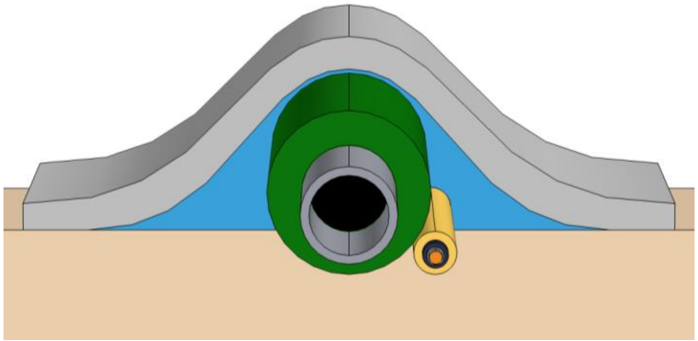

Figure 4: DEH covered by mattresses.

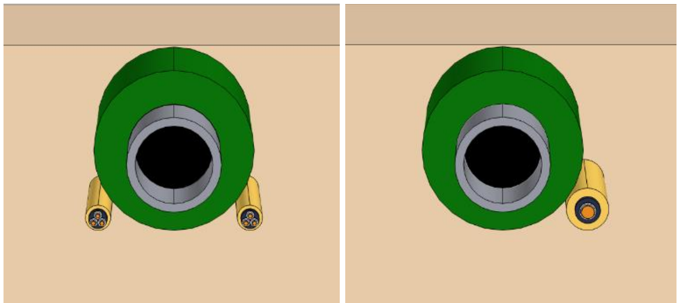

Figure 5: Buried top of pipe with heat tracing (left) and DEH (right).

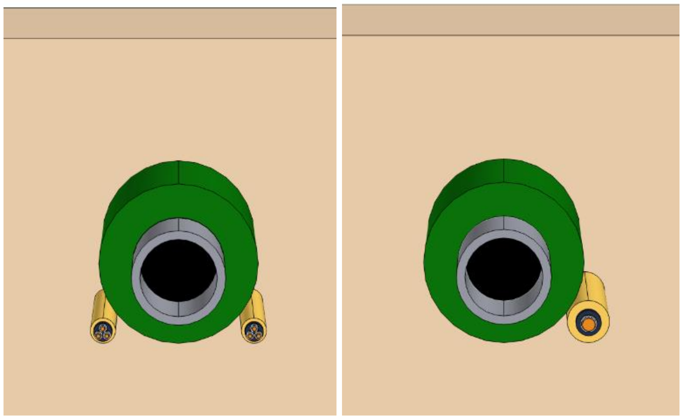

Figure 6: Buried 1 m to top of pipe with heat tracing (left) and DEH (right).

RESULTS FROM CASE STUDIES

Heating capability of heat trace cable

The heating capability of the heat trace cable depends highly on pipe configuration, layout and the temperature limit of the power cable itself. For the base case configuration, fluid temperatures of 15, 22 and 24 °C can be reached for “buried top of pipe”, “mattress” and “buried 1 m”, before exceeding the temperature limit of the heat trace cable, see Figure 7.

DEH can heat the fluid temperature considerably more than trace heat cables. In this work however, DEH is only compared directly to the heating capability of the trace cables. Therefore, no separate fluid temperature graph is added for DEH in Figure 7.

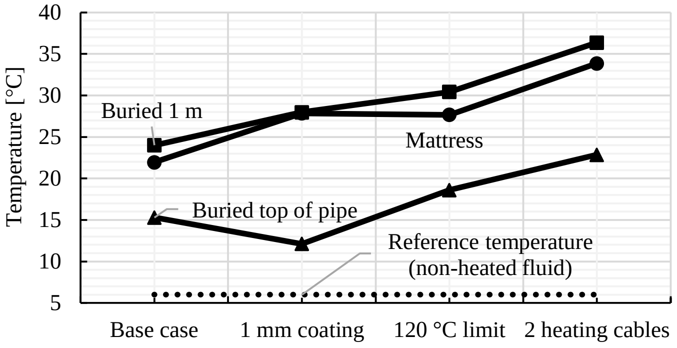

Figure 7: Fluid temperature for trace heat cables.

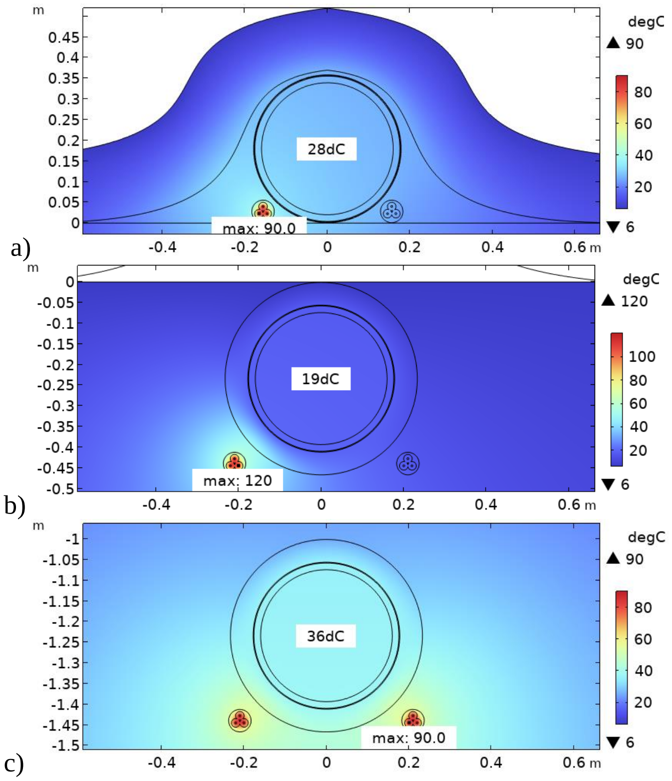

Figure 8: Temperature plots for a)" Mattress, 1 mm coating", b) "Buried top of pipe, 120°C" and c) "Buried 1 m, two heating cables".

If the flowline coating thickness is 1 mm instead of 55 mm, a fluid temperature of about 28°C can be reached for "buried 1 m" and "buried top of pipe". This is a result of the reduced thermal insulation between the flowline and the cable. For the case "buried top of pipe", fluid temperature is instead reduced by a few degrees. In this case, the reduced insulation to ambient exceeds the heat contribution from the reduced separation between the flowline and the cable.

If a 120 °C power cable can be used in preference of a 90 °C cable, fluid temperatures of 19, 28 and 30 °C can be reached, for “buried top of pipe”, “mattress” and “buried 1 m”, respectively. Using two heating cables (90 °C limit) results in fluid temperatures of 23, 34 and 36 °C. See Figure 8 for various temperature plots.

If the sensitivity parameters were combined (1 mm coating thickness, 120 °C limit of cable insulation and two heating cables), the fluid temperature could be increased up to 54-56 °C for "mattress" and “buried 1 m”, respectively. If maintaining 55 mm coating thickness (120 °C insulation and two heating cables), 44-49 °C is reached for the same two cases.

Power

The power requirement to reach the fluid temperatures in Figure 7 is in the range 76-153 kW/km for heat tracing, and 49-105 kW/km for DEH, see Figure 9. This is the power at which the heat trace cable reaches its thermal limit of 90 °C or 120 °C. The temperature of the piggyback cable is less than 90 °C for all calculations. For the case with two heat trace cables, the power demand is given for the two cables combined. The highest power demand for one single cable is 105 kW/km (90 °C limit) and 115 kW/km (120 °C limit).

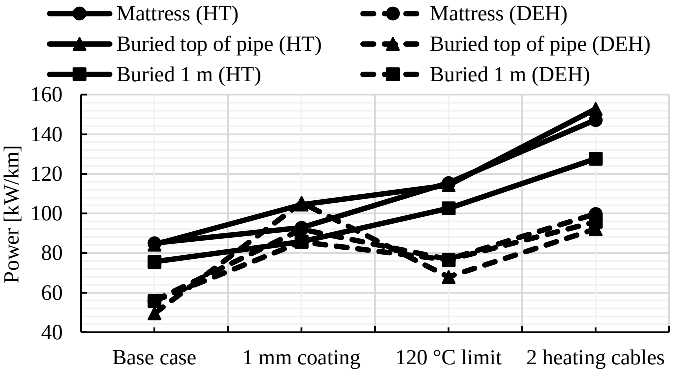

Figure 9: Power demand of trace heating and DEH to reach fluid temperatures in Figure 7.

Depending on the flowline configuration, the difference in power consumption between heat trace cables and DEH is considerable, see Figure 10. For the base cases, the DEH power consumption is 59-74% that of trace heating. The lower power consumption of DEH is because parts of the heat is generated in the steel wall, that is closer to the fluid and within the thermally insulated flowline coating. In contrast, all heat from the heat trace cables must be conducted through the flowline coating, leading to higher heat losses to the surroundings. For thin coating, power demand is similar for each of the heating systems.

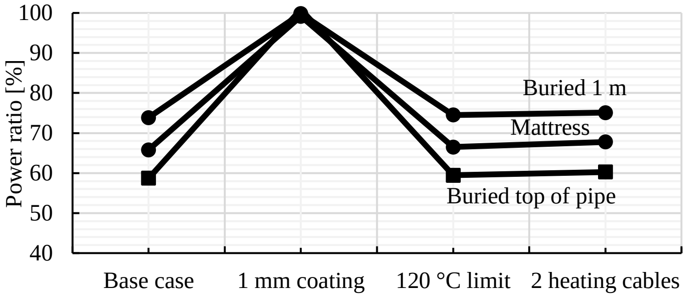

Figure 10: Power demand ratio (DEH/trace heating) to reach the fluid temperatures in Figure 7.

HEAT TRACE CABLE DESIGN

The electrical system design parameters of the heat trace cables vary depending on the conductor cross-section. In this section, two conductor cross-sections are considered: 16 and 50 mm^2. The phase current and phase-to-phase voltage of these heating cables vary in the ranges 130-320 A, and 195-410 V/km for three-phase systems. See Table 4. The current and voltage ranges are for the power considered in the case studies, 76-115 kW/km, for each cable. The heat trace system is assumed to be purely resistive.

For a 50 km flowline, the system voltage varies between 10 and 21 kV, which is within medium voltage classification. Medium voltage is not strictly defined but is often used for cables from about 1 kV up to 36 kV. As insulation thickness increases at higher voltages, there will be some more thermal resistance in the cable itself, reducing the heating of the fluid. It is also worth noticing that as voltage increases, the cable cross-section must increase to reduce the voltage stress (kV/mm) close to the cable core.

Cables with larger cross sections can also be used at reduced system voltage but at increased current. Obviously, the total power requirement is independent of the conductor cross-section.

Table 4: Heat trace cable design parameters. Conductor cross section, power, phase current and phase-phase voltage.

Cross section [mm2]	Power [kW/km]	Current [A]	Voltage [V/km]
16	76	131	334
50	76	225	195
16	125	168	429
50	125	289	250

DISCUSSION

Trace heating cables can be attractive to mitigate hydrate and wax formation in wet insulated subsea flowlines. There are however some limitations that reduce the application range, such as installation complexity especially at deep waters, thermal insulation (mattrasses or soil embedment), low efficiency and thermal limitations of the heat trace cable itself. It is therefore expected that other flow assurance methods are preferable for most flowlines.

The heating efficiency is very low for heat trace cables placed outside the flowline coating. Heat trace cables typically require 25-50% more power than DEH for the case studies considered in this article. This is because all heat in the heat trace cables is developed in the conductors, in contrast to for example DEH, where part of the heat is developed in the flowline steel wall. Heat trace cables for wet insulated flowlines are never more efficient than DEH.

With respect to the heat trace cable itself, the thermal limit (typically 90 °C), governs the maximum heating capability. In DEH systems, the conductor cross-section can be increased to reduce losses and hence conductor temperature. There exists a wide variety in high-temperature cables, but these can often only hold a few kilovolts.

For flowlines that can accept the limitations above, heat trace cables may be attractive. A main advantage is that there is no need for connections or modifications of the flowline to accommodate for the heat trace cables. Heat trace cables are therefore attractive for retrofit installations, but also in new installations where the flowline can be buried or where external insulation such as mattresses or rock dump can be accommodated for. Heat trace cables are as relevant onshore as for offshore installations. The heat trace cable design is flexible and can be optimized for each installation.

DEH systems have fewer restrictions to the flowline configuration than heat trace cables. The flowline and piggyback cable can for example be exposed to seawater. The flowline should however have a coating thickness of minimum a few millimeters to limit power consumption. Parts of installation is complicated (especially for retrofit) as one power cable must be connected to the flowline in the near and one in the far end. Also, anode banks must be installed to the flowline close to the cable connections.

The appropriate power cable design depends on e.g., installation restrictions. Commercially available three-phase subsea power cables with armor (normally used by power utilities) are regularly used at water depths of about 500 m. Power cables have been installed at water depths of more than 2,000 m. For shallow waters or onshore, simple cable designs that are commercially available, such as single-core cables, can be used.

CONCLUSIONS

Heat trace cables can be attractive to maintain the mixtures of oil, gas and other substances in onshore or offshore flowlines at elevated temperatures. In this work, the trace heat cables are placed next to the flowline to be heated (outside the flowline coating). For such design, trace heating is only applicable when the flowline and the cable are buried in the seabed (from around one meter) or covered by insulation mattresses. Installation of the heating cables, installation tolerances and low efficiency are the main challenges of the evaluated heat trace concept.

Case studies of a 14" flowline with trace heating located next to the flowline indicate that:

- Fluid temperatures can be elevated by heat trace cables from 6 °C (ambient) to 25-55 °C, depending on thermal conditions, number of heat trace cables and temperature limit of the heat trace cables.
- The heat trace cables can typically provide around 100 kW/km each before being thermally overloaded.
- Heating efficiency of trace heating is lower than for DEH. Heating by DEH typically require 25-50% less power to reach the same fluid temperature as trace heat cables.
- The power requirement in the case studies varies from 76 to 115 kW/km. With conductor cross-sections of 16-50 mm^2, the conductors must carry a current in the 130-280 A range and hold a voltage of 200-400 V/km. Commercial heat trace cables are available for flowline lengths including at least 50 km.

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