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WATER TREEING AT HIGH HYDROSTATIC PRESSURES AND TEMPERATURES

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ABSTRACT

A very special application for XLPE cables has been developed for offshore use. High voltage is used in order to prevent blocking of oil transport pipes. A high voltage is used to heat the steel pipes to a moderate temperature. In this way the increased temperature melts eventual wax decomposition on the inside wall of the oil pipe. However, this use demands for not metallic water protected XLPE cables. And the use is also requiring high conductor current in order to heat the pipe. A typical water depth where such system is installed is approximately 300 m.

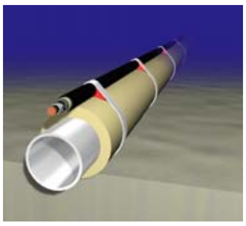
XLPE cables have been aged at temperatures up to 90 ^{0}C, different electric stresses and exposures for hydrostatic pressures up to 30 bars. Bow tie trees are initiated rapidly after the ageing is started. Breakdown strength is reduced by a factor of approximately 3 the first year. No significant vented water tree growth is observed, even after almost 2 years of ageing. This is an unexpected observation when compared to utility experiences.

KEYWORDS

XLPE cables, wet ageing, hydrostatic pressure, high temperatures, water treeing.

INTRODUCTION

Traditional methods of clearing pipelines of wax and hydrate deposits are by use of chemical inhibitors. However, these methods are expensive and represent a risk to the environment if leakage should occur and require comprehensive operational procedures.



a)

b)

Figure 1: a) Schematic drawing of the DEH cable strapped to a flowline. b) Example of paraffin blocked pipeline.

The Direct Electric Heating (DEH) system [1, 2] is based on the fact that an electric alternating current (AC) in a metallic conductor generates heat. The heating system is usually from the platform power supply, from which feeder cables provide the electric power to the heating system. One of the two single core feeder cables is connected to the near end of the pipe, and the other to the forward conductor (piggyback cable) that is connected to the utmost end of the pipe. The cable connected to the far end is mounted parallel and close to the pipe as shown in Figure 1 a) and Figure 2.

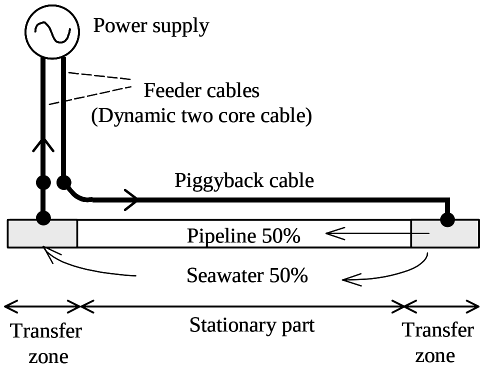


Figure 2: Schematic drawing of a DEH cable piggybacked to a pipeline.

Up to now the DEH system has been installed on flowlines of lengths up to 15 km. In this system the heated pipeline is an active conductor in a single-phase AC electric circuit, together with a single core high voltage extruded cable strapped (piggybacked) to the heated flowline. For new projects with flowlines exceeding 40 km [2], the insulating outer sheath and the metallic ground screens can be replaced by a semi-conductive outer sheath for a continuous transfer of capacitive currents to seabed, or to clay for buried sections. This can be essential to avoid high voltages subjected to the metallic ground screens. Due to the high temperatures of the crude oil, thermal insulating properties of the clay and heating of the cable conductor, relative high temperatures can be subjected to the cable materials.

However, in order to optimise the DEH system no metallic water blocking of the cable sheath can be used. A wet cable construction has to be applied at high temperatures direct installed in sea water. Hence, water tree growth has to be considered as a precursor to cable failure.

Water treeing has been studied for more than three decades. Material aspects have been evaluated with respect to electric stress, temperatures, frequencies, etc. Reference for testing regimes can be made to both international literature and standards. SINTEF Energy Research has been active ever since the middle of the seventies; both with respect to tests that investigates water tree initiation and growth dependency upon ageing regimes and performing long term tests on manufactured cables.

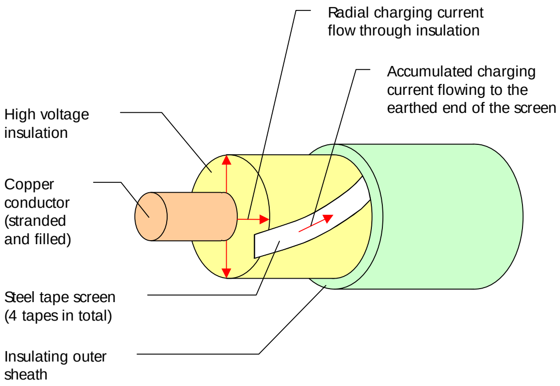
In addition SINTEF Energy Research also performs forensic investigations on service aged cables. Water treeing is the major cause of service failures of XLPE cables.

The statements above are generally related to utility land buried XLPE medium voltage (12 and 24 kV) cables. However, SINTEF Energy Research has also performed investigations of XLPE cables after more than 20 years of submarine service. Water treeing is still the major ageing mechanism in these cables.

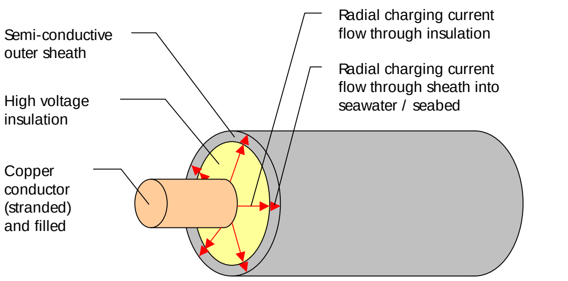
The main objective of this paper is to study water tree initiation and growth at test conditions governed by the special service conditions of DEH cables.

EXPERIMENTAL APPROACH

Up to now XLPE cables with a principal design as shown in Figure 3 [2] have been used for the DEH installations.



a) Conventional Piggyback cable design (limited cable length)



b) Novel Piggyback cable design for Tyrihans DEH (long cable length)

Figure 3: Principal DEH cable designs.

As can be seen in Figure 3 no metallic water blocking is included in the cable sheath construction. Water will therefore eventually diffuse into the cable and the insulation material will become wet. As model for the actual DEH cable an XLPE cable as shown in Figure 4 was used to study the water tree growth.

No external cable sheath was applied on the test cables. Water was in direct contact with the insulation screen during the entire ageing.

As almost all submarine cables have copper conductors this was also used in this case. The cable was a 6/10 (12) kV XLPE cable with 95 mm^2 copper conductor.

Figure 4: XLPE cable (12 kV cable / 95 mm^2 Cu) used for the water treeing tests – 3.4 mm insulation thickness.

Ageing is performed in different pressure vessels depending upon the actual hydrostatic pressure during the long term ageing. One of the 30 bar vessels is shown in Figure 5.

Figure 5: Stainless steel pressure vessel (750 l) for 30 bar long term ageing test.

Approximately 2x100 m cable core was aged; two different ageing voltages were applied. One cable was aged at a relatively high voltage and one at a significant lower voltage. This was done in order to simulate the varying voltage of the cable along the flowline length: Rated voltage at the end of the power supply and zero voltage (grounded) in the far end. The cables were coiled on stainless steel drums with diameter 0.5 m and placed inside the pressure vessel.

The ageing was performed at the following conditions:

- Temperature: Constant 90 ^{0}C or cyclic 90/65 ^{0}C.
- Voltage 0.85 and 3.4 kV/mm
- Hydrostatic pressure: 1, 10 and 30 bar
- Aged in tap water
- Oxygen content: 8 ppm

The high voltage connections were placed at atmospheric conditions outside the pressure vessel in ambient air.

Evaluations after ageing were performed by residual AC breakdown strength tests and water treeing investigations. The AC breakdown tests were started at $3U_0$ (18 kV) and the voltage was increased by U_0 (6 kV) every fifth minute until breakdown occurred.

Three to five test objects (5 m active test lengths and 0.5 m deionised water terminations) were tested to breakdown at each of the chosen ageing times. Water treeing investigations were performed on 10 mm long sections, including the breakdown sites, after being stained in methylene blue stain solution [3]. Water trees both from the screens (vented water trees) and in the bulk of the high voltage XLPE insulation (bow-tie trees) were registered.

EXPERIMENTAL RESULTS AND DISCUSSION

Ageing tests at constant high temperature

Figure 6 shows results from AC breakdown test for up to 12 months of ageing. The 30 bar tests have only been aged for 5 months yet.

It can be seen that the breakdown voltage is initially about 65 kV/mm (175 kV), and decreasing to about 20.5 kV/mm (55 kV) after 12 months of ageing (63 %-values from Weibull statistics). The 30 bar tests at approximately 6 months ageing indicates that no acceleration of water tree growth has occurred at this increased hydrostatic pressure.

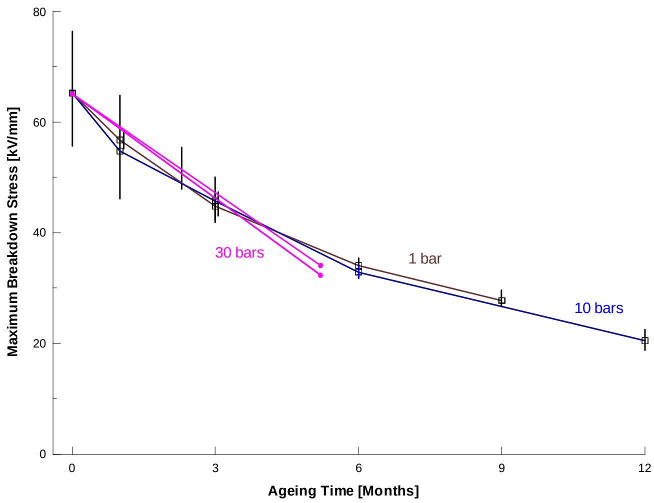


Figure 6: AC breakdown stress reduction as a function of hydrostatic pressure and time.

No significant difference was observed between the breakdown stresses for the samples up to 5 months aged at 1, 10 and 30 bars. At 1 and 10 bars this applies at least up to 9 months.

Table 1 shows the water treeing results of the cables shown in Figure 6. Bow tie trees were detected in all samples investigated. Vented water trees, however, was only detected in rare occasions, these trees were always short.

Table 1: Water treeing results

Hydro-static pressure [bar]	Ageing stress [kV/mm]	6 months		9 months		12 months	
		BT l_{max}	VT l_{max}	BT l_{max}	VT l_{max}	BT l_{max}	VT l_{max}
1	¼E_0	-	-	-	-	-	-
	$2E_0$	-	-	260	0	-	-
10	¼E_0	-	-	-	-	-	-
	$2E_0$	480	50	-	-	1040	0
30	¼E_0	600	0				
	E_0	520	0				

- : Water treeing investigations not performed
BT : Bow-tie trees
VT : Vented water trees

When Figure 6 and Table 1 are combined it can be observed that the AC breakdown strength is reduced by a factor of approximately 3 this first year of ageing. The main reason for this reduction is the growth of bow tie trees. Figure 6 shows that rate of decrease is reduced the second half year compared to the first. This is as expected when compared to standardized 2 years long term ageing tests [X]. The 30 bar tests are still in progress; only results up approximately 6 months was known when this paper was written.

The longest observed bow tie tree is shown in Figure 7. It can be seen that this bow tie tree is growing from an inhomogeneity within the bulk of the XLPE material.

Figure 7: Longest bow-tie tree detected (1.04 mm long) within the insulation at 10 bar and 12 months of ageing.

From what is seen from service failures on-shore, it was expected that vented water trees would be the main ageing mechanism. However, only one single "long" vented water tree was observed. This tree was observed after 6 months of ageing with a length of only 0.25 mm. No vented water trees were observed after 9 and 12 months of ageing.

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Ageing tests at cyclic varying high temperatures

After discussing possible service conditions with the user it was decided to implement ageing tests with cyclic varying temperatures. The most interesting condition in the first place was cycling between 90 and 65 ^{0}C. One cycle was composed by 24 hours heating from 65 to 90 ^{0}C immediately followed by a 48 hours cooling from 90 to 65 ^{0}C. This procedure was a simulation of service conditions if the cable was totally covered by clay.

The results from the ageing tests are shown in Figure 8.

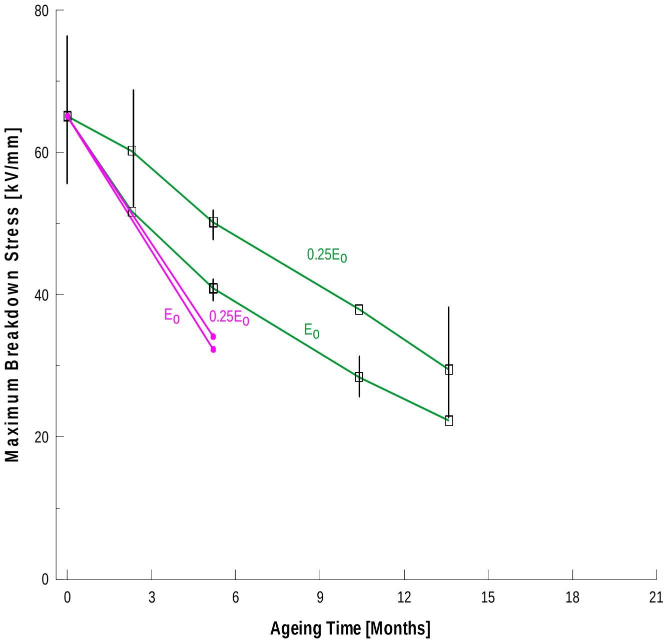

Figure 8: AC breakdown stress reduction as a function of time. The tests are all performed at 30 bar.
Green curves: Cyclic temperature variations (65/90^{0}C)
Red curves: Aged at constant 90^{0}C

Water treeing results are shown in Table 2.

Table 2: Water treeing results; cyclic ageing temperature compared to constant high ageing temperature.

Ageing temperature [^{0}C]	Ageing stress [kV/mm]	6 months BT I_{max}	6 months VT I_{max}	13 months BT I_{max}	13 months VT I_{max}
Cyclic	¼E_0	190	0	580	0
	E_0	800	0	680	0
Constant	¼E_0	600	0		
	E_0	520	0		

BT : Bow-tie trees
VT : Vented water trees

Based on the AC breakdown values ageing at constant high temperature appear to result in a more rapid degradation of the XLPE material than ageing at cyclic temperatures between 65 and 90 ^{0}C. This is, however, not the case for the water treeing observations. However, this may be due to statistical variations; no traces of the reason for the breakdown was observed in any of the breakdown channels, e.g. the size of the actual cause of the reduced AC breakdown voltage has not been found.

In this case no vented water trees were observed at all.

The difference between the two low stress ageing curves is remarkable. It appears that the water trees had grown much faster in the constant temperature ageing set-up than the test at cyclic temperatures. Up to now no plausible explanation is established.

Ageing tests at cyclic varying high temperatures followed by constant temperature long term service

During the project a service pattern including sporadic use of the DEH cable the first 15 to 20 years followed by a continuous use of the DEH cable for several years at the final stage of the oil well. The power demand in this final stage of the DEH cable use may be reduced somewhat compared to the initial demands. However, during these tests a conservative approach was chosen, the cable has to withstand an ageing at full load; e.g. service at 90 ^{0}C for several years. The results from this test are presented in Figure 9 and in Table 3.

Figure 9 shows that the rate of AC breakdown strength reduction has leveled out after a little more than 1 year of ageing. Also the differences between the two curves (¼E_0 and E_0) seem to vanish. This is also reflected in Table 3 where it can be observed that the water trees have stopped growing in this period of time.

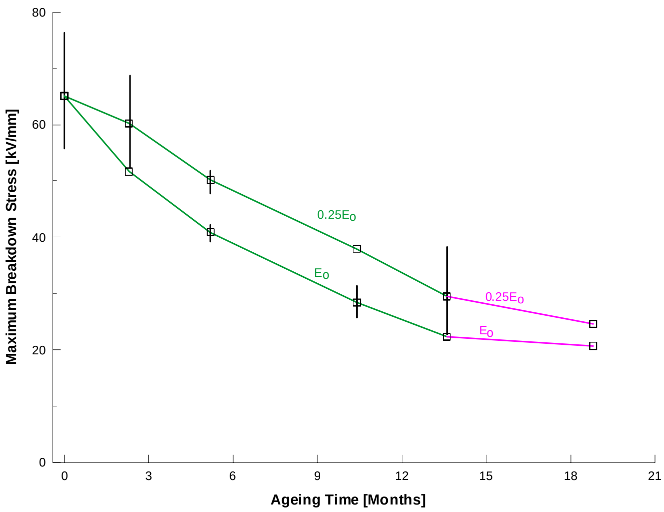

Figure 9: Ageing first with cyclic temperature variations between 65 and 90 ^{0}C (green curves). Directly followed by continuous ageing at 90 ^{0}C (red curves).

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Table 3: Water treeing results; cyclic ageing temperature directly followed by a constant high ageing temperature

Ageing tempe-rature [^{0}C]	Ageing stress [kV/mm]	13 months		19 months	
		BT I_{max}	VT I_{max}	BT I_{max}	VT I_{max}
65/90-90	¼E_0	580	0	600	0
	E_0	680	0	720	0

BT : Bow-tie trees
VT : Vented water trees

The ageing is still going on. However, no results with longer ageing times were ready at the time when this paper had to be finished.

Table 3 shows that also in this case no vented water trees were observed. Indications about reduced vented water tree growth at increased ageing temperatures have previously also been reported in [4, 5].

CONCLUSIONS

After almost two years of ageing at very high temperatures still the AC breakdown strength is maintained at a level of approximately 20 kV/mm. Compared to the service stress this seems to indicate reasonable long cable life.

Ageing does not initiate vented water trees. This was un-expected when compared to premature ageing problems of onshore XLPE cables. Growth of bow tie trees governs the ageing of XLPE direct electric heating cables.

Hydrostatic pressure up to at least 30 bars has not resulted in significant changes of the water treeing degradation.

The DEH cable appears to be well fitted for continuous use during tail production of oil. No accelerated ageing occurred when the use was changed from a few days at the time to a continuous use at high cable loads.

REFERENCES

[1] S.Hvidsten, J.K.Lervik, H.Kulbotten, J.T.Benjaminsen, K.Olafsen, L.M.Lundegaard, A.H.Børnes: "HV Cable Design Applicable for Direct Electrical Heating of Very Long Flowlines". Oceans'04 MTS/IEEE, pp 257-263, Nov. 2004, Kobe, Japan

[2] A.Nysveen, H.Kulbotten, J.K.Lervik, A.H.Børnes, M.Høyer-Hansen, J.J.Bremnes: "Direct Electric Heating of Subsea Pipeline – Technology Development and Operating Experience". IEEE Trans. on Ind. Appl. Vol.43, No.1, Jan/Feb 2007

[3] P.B.Larsen: "Dying Methods Used for the Detection of Watertrees in Extruded Cable Insulation". Electra No.86, pp 53 – 59, 1983

[4] V.A.A.Banks, H.Faremo, E.F.Steennis: "An Accelerated Ageing Test on the Basis of 500 Hz for Water Treeing in Cables". Jicable'95, Paper No. B.3.3, Versailles, France, June 1995

[5] E.F.Steennis, H.Faremo: "State of the Art of Water Tree Testing on Cables – The Development of an Accelerated Ageing Test". CIGRE 1992 Session, Paper No. 15/21-03, Paris, Aug/Sept 1992