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CP DESIGN OF A SUPER 13% CR FLOWLINE

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ABSTRACT

Mechanical and corrosion properties and overall cost of weldable 13% Cr stainless steel make the material an attractive alternative for subsea production flowlines. However, the material may be susceptible to hydrogen cracking in combination with cathodic protection. This paper describes the design and qualification of a diode controlled cathodic protection system for the Fram Vest 13% Cr production flowline. The flowline was installed in the North Sea in the summer of 2003 and has a protection system consisting of polypropylene thermal insulation and sacrificial anodes connected to the pipeline via diodes and stainless steel cathode plates. The design potential of the pipeline is in the range -600 to -750 mV vs. Ag/AgCl/sea water reference electrode.

Keywords: cathodic protection, CP, 13% Cr, flowline

INTRODUCTION

The Fram Vest field is located in the Norwegian Trench at 355 to 360 m water depth, approximately 70 km north-west of the city of Bergen and 20 km north of the Troll C platform.

The field is developed with subsea satellite wells and the reservoir fluid is transported to the Troll C platform for stabilization. The multiphase 13% Cr flowline is designed to transport 10000 m^3 oil (and water) and 2 million m^3 gas/day. The water content varies from more than 200 m^3/day early production to approximately 120 m^3/day through the 25 years design life. Reservoir pressure is maintained by injecting 3 million m^3 gas/day through a dedicated carbon steel flowline.

The produced fluid is sweet with a maximum of 3.2 ppm H_2S in the gas phase and 3.15 mole % CO_2.

Norsk Hydro is the operator for the Fram Vest development and the other partners are Gaz de France Norge AS 15%, Idemitzu Petroleum Norge AS 15%, Statoil ASA 20% and Mobil Development Norway AS 25%. The pipeline EPCI contractor was Technip Offshore Norge AS.

PIPELINE DESIGN PARAMETERS

Some of the design data for the Fram Vest production flowline are given in Table 1.

The expected internal corrosion on carbon steel may be controlled with inhibitor injection. However, an overall cost comparison shows that using a stainless steel flowline is advantageous. A reduced wall thickness, better mechanical properties and enhanced utilization, favorable installation time and reduced chemical consumption and environmental aspects are the main factors contributing positively. The main disadvantage in using 13 % Cr stainless steel is its susceptibility to hydrogen induced cracking when subject to high active strain in combination with hydrogen and low tolerance to sulphide. A material and welding qualification programme including SSC testing was considered necessary.

Following reports of failures due to hydrogen from the cathodic protection system of 13% Cr flowlines installed recently, it was decided to modify the corrosion protection system for the Fram Vest production flowline. In addition to a modification in the CP design this included the use of readily available 25% Cr pup pieces with heavier wall thickness at anode connections to reduce the strain concentration in the areas most critical with regards to hydrogen induced effects, and some cladding with austenitic filler material.

BASIS FOR MODIFYING THE CATHODIC PROTECTION SYSTEM

Modification of the corrosion protection system was based on two realizations:

- All reported failures are related to hydrogen embrittlement. Therefore production of hydrogen from the cathodic protection system should be eliminated.
- All hydrogen enters the material through openings, deliberate or accidental, in the coating. The number and size of such openings should therefore be minimized by improving the quality of the coating (work) and reducing the number of penetrations for electrical leads.

All conventional cathodic protection design parameters were challenged in order to reduce the risk of hydrogen production and diffusion into the steel. This included protection potential, cathodic current densities, number of and distance between anodes and coating deterioration including field joint coatings.

The eventual protection method consists of a diode controlled cathodic protection system. Conventional aluminium sacrificial anodes are connected to the pipe via diodes to increase the potential above the hydrogen production limit. Stainless steel cathode plates are installed in series with the anode/diode assembly. This ensures a minimum current through the diodes and that the potential on the pipeline will always be more positive than the anode potential. If the cathode plates were not used and the pipe did not draw much current (e.g. due to a perfect coating), the potential drop over the diode would be almost zero and the measured potential close to the anode potential. From a monitoring point of view, this potential measurement would be the same as if the diode was short-circuited and hydrogen production could occur.

PROTECTION POTENTIAL

For cathodic protection design the following potential range was selected:

- The maximum design potential is -600 mV Ag/AgCl/sea water. This potential will give protection against crevice, pitting and sulfide corrosion.
- The minimum design potential is -750 mV Ag/AgCl/sea water. This potential is higher than the water reduction potential at the operating conditions.

Due to natural variations in coating breakdown and cathodic current consumption, the potential drop over the diode cannot be predetermined accurately. For this reason the acceptable measured potential range of the installed pipeline is -550 to -800 mV.

During qualification testing under laboratory conditions, the maximum protection potential was determined to be -450 mV. However, during a full-scale test outside the harbor in Trondheim, Norway, the pipes polarized to this potential were found to reverse the direction of the current, and to have a lower free corrosion potential when the potentiostatic control was switched off. This was found being related to SRB activity, which is not present at the offshore field. Nevertheless, the design potential was lowered accordingly.

CATHODIC CURRENT DENSITIES

For a fully buried pipeline at ambient temperatures, the current density requirement in the Norsok M-503 standard is 20 mA/m². At temperatures above 25°C, the standard requires an increase of the current density of 1 mA/m²°C. For the Fram Vest flowline this would give a design current density requirement for bare steel of 90 mA/m².

In the design of a cathodic protection system with diodes installed in series with the anode, the actual current in the system is essential in order to predict the potential level on the pipeline. In order to determine the most negative potential, it is also important to have information on what the lowest expected current density in such a system is.

The testing of the current density for buried conditions was performed both in the laboratory and in a full-scale test with 6 pipes at the Trondheim Harbor. The testing was undertaken at pipeline internal temperatures between 5°C and 95°C, and for electrochemical potentials between –400 mV and –800 mV Ag/AgCl. In the laboratory, current density testing was performed in mud from the fjord of Trondheim and in mud from the Fram Vest field.

The testing showed that the current density for a buried flowline is much less than the design data given in the Norsok M-503 standard. In particular, the increase in the current density requirement with the temperature was found to be overly conservative.

Based on the results from the testing, it was decided to use one design current density for all temperatures for the weight design. For the sensitivity calculations a range of current densities was applied to secure that the potential of the pipeline will operate within the design limits even at extreme variations in the current.

DESIGN CALCULATIONS

Coating Breakdown Criteria

Conventional CP-design in Norway follows recommendations in Norsok M-503 and DNV RP B401. Coating breakdown according to these documents would be several percent. Other design standards use lower coating breakdown criteria for thermally insulated pipeline. Based on the coating system selection and the quality control during coating the design recommendation in ISO 15589-2 was used. The entire pipeline was installed by the reeling method during three offshore trips, which means that all welds were coated onshore except for the limited numbers of offshore welds. The coating quality on the majority of the welds was therefore similar to the pipe coating. The coating breakdown criterion used was 0.33% mean and 0.45% final.

The number of anodes was reduced significantly by this coating breakdown criteria decision, and the distance between them was increased to 960 m instead of the conventional 200 m. The increased anode spacing gave less coating penetrations caused by anode electrical connections and increased the overall quality.

Sensitivity and Attenuation Calculations

In addition to the regular CP design to determine the weight and size of anodes, attenuation calculations were performed to design the anode spacing and to assess the potential levels on the flowline throughout the operational life. In combination with sensitivity considerations regarding anode potentials, cathodic current densities, external coating temperature and coating degradation, the attenuation calculations were applied to find the most optimum cathode plate dimensions.

The total potential drop was calculated with:

$$dE(total) = dE(diode) + dE(anode) + dE(pipe) + dE(seawater) \quad (1)$$

where:

dE(diode): Potential drop over the diode
dE(anode): Potential drop close to the anode
dE(pipe): Potential drop in the pipe material
dE(seawater): Potential drop in the seawater (electrolyte)

The dominating factor of dE(total) is the potential drop over the diode, dE(diode). The characteristic for a typical diode is shown in Figure 1. Even though a diode has a more constant potential drop for varying currents compared to a resistor, the variations are significant in a CP design perspective. Also, the variation in outside flowline temperature between operating and shutdown conditions causes variations in the diode potential drop.

The potential drop caused by the anode resistance did to some extent contribute to the dE(total), whilst the potential drop in the pipe and seawater was almost negligible.

In order to determine the maximum cathode plate size, the following input was applied to the calculations:

- Lowest possible current density
- Maximum calculated external temperature of the flowline
- Zero coating breakdown
- Anode potential of –1050 mV Ag/AgCl
- Minimum potential of –750 mV Ag/AgCl

The maximum cathode plate size was calculated by the following input:

- Highest possible current density
- Maximum coating breakdown
- Anode potential of –1000 mV Ag/AgCl
- Lowest calculated temperature
- Maximum potential of –600 mV Ag/AgCl.

Based on a series of cases reflecting the relevant stages in the operational life of the flowline, the most optimal cathode plate was found.

INSTALLATION

Anode/Diode Assembly

A schematic presentation of the anode – diode – cathode plate system and connection to the flowline is shown in Figure 2.

The diode assembly consisted of two diodes in a parallel connection. A parallel connection of the diodes gave less variation in the potential drop over the diodes with increasing current and, hence, a better basis for design. The parallel connection also served as a back-up if one of the diodes fails open. The diodes were installed in a tube for mechanical protection and sealed to prevent ingress of water and influence from the hydrostatic pressure. Electrical connection between the anode and the cathode plate was secured by wires from the anode through the two diodes and further to the cathode plate.

By increasing the gap between the two half shells of the bracelet anode, the diode assembly was fitted to the protruding insert steel of the anode. Two cables from the diode assembly were welded to each shell of the cathode plate. Another two wires were installed to secure the electrical connection between the cathode plate and the flowline.

The diode assembly was welded to the anodes onshore and thoroughly controlled before delivery to the reeling vessel.

Cathode Plates

The cathode plate was installed to secure a minimum current through the diode assembly even at zero coating breakdown. This secures that the potential of the flowline at all times during operation is at a level more positive than –800 mV. The surface area of the cathode plate also makes it the dominating current drain source through the lifetime and makes the influence of the increased current requirement due to coating breakdown less on the potential level.

To reduce the overall length of the cathode plates and improve ease of installation, they were designed as “double deckers” with two plates lying on top of each other, as indicated in Figure 2. The distance between the plates is 70 mm and the surface area of all three sides of the plates is utilized in the design. To prevent current drain to the plate side facing the flowline coating and to secure a good adhesion, this side was coated with a 3 mm rubber coating.

Welding Sequence

The anode with diode package was supplied with electrical leads. The leads were connected to the cathode plates by welding after the anode and cathode had been mounted on the pipe offshore. The cathode plates were then to be connected to the pipe with welding another set of electrical leads. The welding current could damage the diodes. The welding sequence and conscious selection of weld ground connection was thus very important. All diode packages were checked offshore before and after welding. Of a number of 28 anodes installed 5 diode packages were damaged after welding and were replaced.

Potential Measurements

The flowline was installed in three sections. Potential measurements were taken immediately after installation of each section prior to trenching. This testing was performed in order to confirm that the diode packages were functioning and that the electrical leads had not been broken before the trenching operation. These initial data confirmed that the diodes performed as expected and that the potential was in the predetermined range.

CONCLUSIONS

The cathodic protection design for the Fram Vest production flowline has shown that it is possible to control the electrochemical potential of a subsea pipeline within relatively narrow limits by the use of diodes. It is, however, essential to have detailed knowledge of the operating parameters for the system regarding internal and external temperature, degree of burial, coating system and current densities in order to detail the design. In the Fram Vest development, a lot of effort has been given to establish these data, specifically related to current densities and protection potential for the 13% Cr material.

The first CP monitoring data after completed installation of the flowline has shown that the potential is within the design window of –600 mV - –750 mV Ag/AgCl.

TABLE 1

DESIGN DATA

Design pressure	Bar	300
Design temperature	°C	100
Dimension OD	mm	340
Wall thickness	mm	15.3
Material		13% Cr stainless steel
Coating		Thermal insulation system
FBE	mm	0.3
Polypropylene solid	mm	5
Polypropylene foam	mm	26
Polypropylene solid	mm	4
Field Joints, FBE+ solid polypropylene	mm	>36
Burial	m	Minimum cover 0.8
CP design		Modified
Installation method		Reel lay
Length	km	24.2

FIGURE 1:

TYPICAL DIODE CHARACTERISTICS

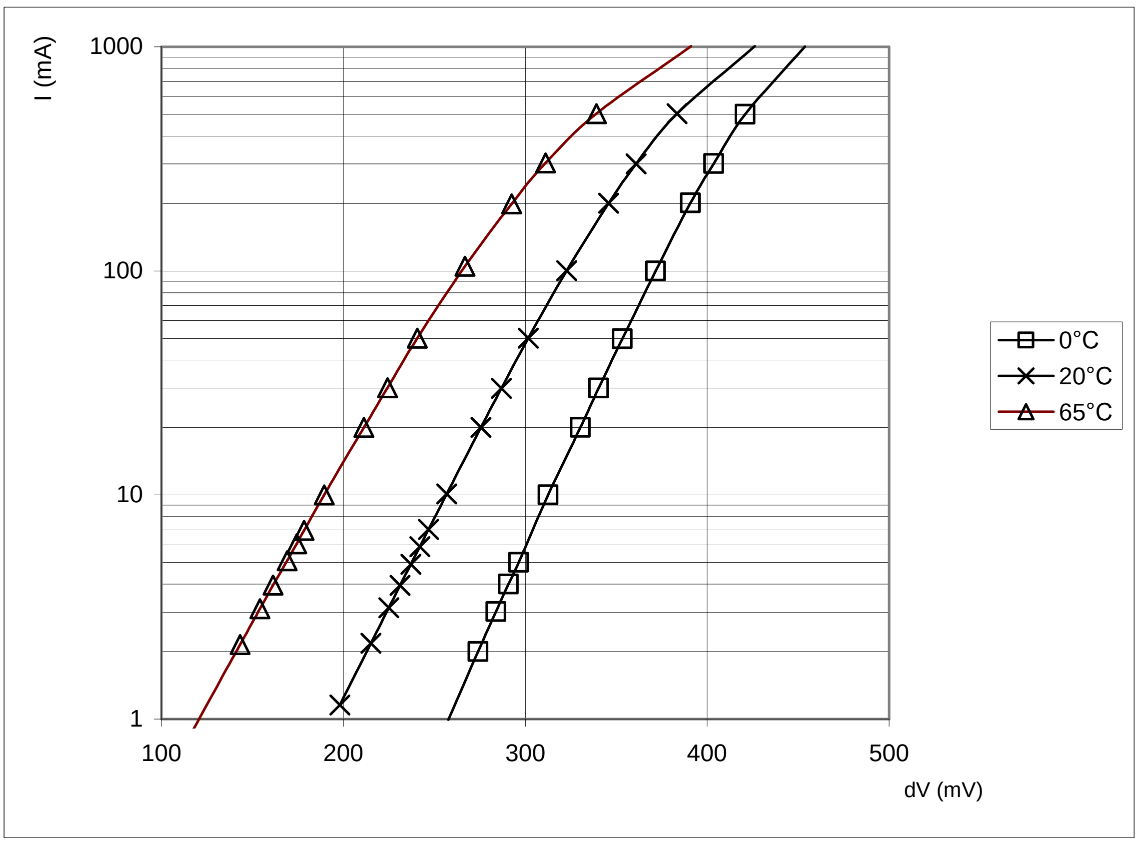

Figure 2:

DIODE ARRANGEMENT, PRINCIPLE SKETCH