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Improvement of Corrosion Protection Efficiency Based on Acombination of Cathodic Protection and Coating: A Case Study of Ajacket Structure, Suction Mooring Pile and Crude Oil Pipeline

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ABSTRACT
The importance of cathodic protection (CP) inpetroleum industry cannot be overemphasized. CP method is widely usedin the industry to prevent steel structures and metal pipelinesfrom corrosion damage. Provision of insulating coating and sacrificial anode for CP system designsignificantly reduces the current demand and anode weight. Regardingoffshore structures, reduction in anode weight is an important factor needed to reduce overall structure weight and drag forces for design reason.For a controlled high weight and long design lifestructures, the combination of coating and CP is mostly cost-effective corrosion control. Coating with combination of cathodic protection doesn't means that the structure surface is completely coated, but by coating most of the structure surface areas, the anode required may be reduced dramatically. The structure surface area in mud, stainless steel area and susceptible damage coating partsshould be consideredas uncoated surface areaduring CP system design.This paper present different technique for CP system designinclusive/exclusive coatingand compare the results with regard to anode weight and associated cost savings.
Keywords: Cathodic,Corrosion, Protection, Coating,Cost, Saving

I. INTRODUCTION

In terms of corrosion locality, marine environment can be divided into atmospheric zone, splash zone, tidal zone, immersed zone, and seabed sediment zone respectively. The unique features of each marine environmental zone, with radical differences in exposure cause significant differences in their corrosion progression [5]. The seabed sediment zone is generally considered to be the least corrosiveness region due to the little presence of oxygen. Coating of offshore structure is mostly used for splash zone and atmospheric zone where cathodic protection is not very effective and corrosion process is very fast [7].Offshore platform and subsea equipment painting are also applied on them in the submerge zones to reduce the current required for the cathodic protection.This paper presentthe differences between coated and uncoated structure.

The combined use of coatings and cathodic protection takes advantage of most attractive features of each method of corrosion control. Coating provides the bulk of protection, while cathodic protection provides protection to flow in the coating. As the coating degrades with time, the activity of the cathodic protection system develops to supplement the deficiencies in the coating. Thus, the combination of coating and cathodic protection generally provides the most economic corrosion protection system [6].

When coating is use in combination with cathodic protection the anode weight can be visibly reduced and result in overall structure weight decrease. This will be beneficial to the structure as there will be less load on the members that make installation easier. Also, since the quantity of anodes has been reducedthe point of welding anode to the structure will be likewise reduced [4]. Thecost of purchasing anode will be greatly reduced and result in cost saving. Though, extra paint will be required, which will increase the cost of structures surface painting.

Application of cathodic protection should be considered as a method for corrosion control, rather than provide full protection for the structure. The technique should not be allowed to replace the selection of highly corrosion resistance materials during the project design stages [4]. Special attention is also essential to prevent corrosion damage before structure installation and the period required for cathodic protection system needs to energize. Also, for a vital structure that needs to withstand high pressure and long design life span, extra thickness may be provided knows as corrosion allowance

In the following sections, the knowledge from several cathodic protection design performed for coated and uncoated structure surfaces will be presented to attempt and discover the optima solution for structure protection from corrosion damage.

COATING BREAKDOWN FACTOR

The Coating Breakdown Factor (fc) can be defined as estimated reduction in cathodic current density due to the application of an electrically insulated coating. The value fc = 0 means the coating is 100% electrically insulating. fc = 1 implies that the coating provides no protection. For example, the mean current required can be reduced by roughly 70% if a “high grade” coating is applied in accordance with DNV RP B401 andDNV RP F103. The coating properties(fc) are referring to coating material, surface preparation and method of application, which can be expressed mathematically with Equation (1.0).

$$f_c = a + b \times t \quad (1.0)$$

where, **t** is coating lifetime in years, **a** and **b** are constant depending on coating properties and water depth as stipulated in RP B40.

To be classified as “high grade” coating, the following criteria have to be satisfied.

- Two or extra layers of marine coating such as epoxy, polyurethane and vinyl based), total nominal DFT minimum 350μm
- Tested for cathodic disbonding in accordance with ASTM G8[2] or similar with a maximum acceptance standard of 10mm disbonding.

Coating of Jacket Structure

The fabricating framework for jacket structures, leg and bracings are rolled and welded before they assembled to complete the structure. For the structural elements in the splash zone (from +4.5 to -1.0m) a protective coating has to be provided and the immersed parts of the jacket may be coated or uncoated depending on the project documentation.The results ofthis studies will demonstrate the best option with regard to the cost benefits for providing coating for the whole jacket structure surface or limiting the coating to the splash zone only.

The reason why the whole jacket structure is not coated may be explained by the extra time that will be required. Hence, the coating is limited to the splash zone since painting the whole structure might be time consuming when project is on the fast track.

Coating of Floating Production and Storage and Offloading (FPSO)Suction Mooring Pile

The basic structure of a suctionmooring pile is a cylindrical unit. The bottom part of the cylinder is open and the top portion is covered. It is partially penetrating to the ground due to its own weight and partly due to suction developed inside the caisson by pumping the water out of the pile. The components of suction apparatus include the pump, suction controller, collection vessel, transfer tubing, suction nozzle and mooring chain.

When fabricating suction pile, cylindrical partrolled and welded before coating is applied to the suction pile parts external surface thatis above the seabed sediment zone. After that the components of suction apparatus will be installed on the top portion that was covered as shown in Figure 1.0.

The part of suction pile located in the seabed sediment zone is uncoated due to low corrosion process in the zone. Also, if the pile is at all coated the coating will suffer serious damage due to the friction force between the pile external surface area and the soil during installation. When we know the total length of the pile, we can also know the length of the pile that is above seabed which is coated and the length of the pile which is under the seabed which is uncoated. In the CP design the external area of the pile in the two zones will be calculated separately and input into design as coated and uncoated area respectively. The suction pile other supportive components surface area will be calculated and input into the CP design. These components include head plate, lateral anchor shell, lowering padeye and mooring chain etc.

Coating of Crude Oil Pipeline

It is required to determine the cathodic protection system for a well-coated crude oil pipeline of 150 mm diameter and 9 km long running from offshore production wellhead to early production facility located onshore. Application of sacrificial cathodic protection system is recommended. The life span of the facility is proposed to be 20 years.

The design mean current density as stipulated in DNV-RP-F103 for buried pipeline as a function of internal product temperature is 0.03 A/m^2. The anti-corrosion coating material is 3-layer Fusion Bonded Epoxy (FBE) and the coating breakdown factors used are selected based on the requirements recommended in DNV RP-F-103.

CATHODIC PROTECTION BASED ON COATED SURFACE

Cathodic Protection (CP) is virtually effective for the buried or immersed steel structures that need corrosion protection and required CP installation as part of the design. The benefit of using an organic coating in addition to CP may be due to the structure large size, complexity and cost saving that is required for the CP system.When painting structural members, some of the coating may be damaged during installation and some parts of equipment may be stainless steel, which might not be coated.All these areas will be estimated and included as uncoating areas in the CP design.

When calculating the structure areas that required cathodic protection the following aspect have to be duly considered:

- Calculate the entire structures or equipment surface area that required to be protected
- Calculate the stainless-steel parts surface area that will be uncoated
- Calculate the area that will be uncoated due to support/member future welds.
- Calculate the area that may be subjected to high wear such as conductors
- Estimate allowance to cover coating damagesand unexpected activities that can damage the coating
- Select the appropriate coating breakdown factor reference to DNV RP B401andDNV RP-F-103
- Perform CP design based on a combination of coated and uncoated structure surface area

During fabrication and coating stages, the structure uncoated surface area should be recorded and confirm that the actual uncoated area is not greater than uncoated areas used in CP design. This actionis to prevent installation of additional anodes to compensate for the countless uncoated areas during project execution.Also, the quality of coating with the breakdown factor use in CP design should also use for the structure coating to substantiate the entire cathodic protection system.

CATHODIC PROTECTION BASED ON COATED SURFACE VS. UNCOATED SURFACE

The cathodic protection design carried out on three (3) different projects will be presented. The three designs were based on DNV RP B401 and DNV RP-F-103. The first example is jacket structures. The second example is FPSO suction mooring pile and the third example is a crude oil pipeline. All the three examples are installed in the Niger Delta, Nigeriawith design life varied from 20 to 25 years.

The jacket structure is a four (4) legged jacket connected to 8 conductors with installation weight of about 9.5 tons excluding piles.The jacket is anchored to the seabed by 4 piles driven to a depth of 70m. The jacket is installed in the Niger Delta in the seawater depth of approximately 97m.The cathodic protection system is designed to guarantee full protection of the structure for 25 years.

The second example is suction mooring pilethat is installed in a 1200m water depth for the attachment of mooring chains of an FPSO. The pile diameter is 6.5meter and 21m long. The pile structure is equipped with several internal stiffeners and padeye for lifting. The design life of the cathodic protection system is 25 years. The CP designis in accordance with the "DNV Recommended Practice RP B401.

The third example is the cathodic protection system for a crude oil pipeline in shallow water of Niger Delta, Nigeria. The pipelineis 6 ins diameter and 9 kilometer long. Only the outside surfaces of the pipeline will be protected by CP. The design life of the cathodic protection system is 20 years.

Area calculations for all the three (3) examples when assumed that the majority areas are coated is presented in Table 1.0. After we include other assembly parts,such as welding and support areas etc. as uncoated, this may be in array of 6% for jacket structure and 16% for FPSO mooring pile.However, the main part of all the three example facilities is coated with high grade coating.

Based on the areas in Table 1.0, cathodic protection calculation was carried out for each of the three (3) examples. The first option we assumedthat most of the surfaces are coatedwith high grade coatingandsecond option assuming most of the surface areauncoated.

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As presented in the Table 2, approximately 2 to 4 times of the anode weight was saved when most parts of the structural steel are coated with a high-grade coating.

The coating breakdown factor f_{cm} and f_{cf} are to be calculated using Equations (2.0) and (3.0) respectively as stipulated in RP B401.

$$f_{cm} = a + \frac{b \times t_f}{2} \quad (2.0)$$

$$f_{cf} = a + b \times t_f \quad (3.0)$$

If the design life (t_f) of the cathodic protection system is longer than actual calculated life of coating system f_{cm} may be determined by Equation (4.0).

$$f_{cm} = 1 + \frac{(1-a)^2}{2.b \times t_f} \quad (4.0)$$

The quantity of current required to protect a structure against corrosionis by using Equation (5.0).

$$I_c = (A_c) \times (f_c) \times (i_c) \quad (5.0)$$

where, I_c is the current density, A_c is the Individual area, $f_c$is coating breakdown factor, and i_c is the design current density.

The total anode mass (M_t) required for design life of a structure can be estimated using Equation (6.0).

$$M_t = (D) \times (I_R) \times \left(\frac{m}{u}\right) \quad (6.0)$$

where,D is the design life, I_R is the required intensity (average),u is the utilization factor, m is consumption rate, $= \frac{8760}{\varepsilon}$

The numbers of anodes (Q) are estimated using Equation (7.0).

$$Q = \frac{M_t}{\text{Anode Unit weight}} \quad (7.0)$$

ANODE CURRENT DRAWING CAPACITY

As a final checkfor CP system design presented in Table 3.0 for the three structures, it is required thatanode current drawing capacity (I_d) is greater than the initial polarizing required current (I_p).This requirement can be checked using the following Equations.

$$Id = \frac{0.25 \times N}{R_0} \quad (8.0)$$

R_0 is anode resistance at initial stage for the short flush-mounted, bracelet,whichcan be determined using Equation (9.0). The anode resistance for long slender stand-off L ≥ 4r is given by Dwight formula in Equation (10.0) as specified in RP B401.

$$R_0 = \frac{0.315\rho}{\sqrt{A}} \quad (9.0)$$

$$R = \frac{\rho}{2\pi L}\left(In\frac{4L}{r} - 1\right) \quad (10.0)$$

$$Id \geq 1.1 \times Ip \quad (11.0)$$

II. CONCLUSIONS

A structure known as coated during cathodic protection system design does not necessary that thesurface of the structure completely is coated. When structure is coated the anode weight can be reduced over many times. For example, in this study the anode weight save for jacket structure is 4.3 times, FPSO mooring pile is 2.5 times, and crude pipeline is 1.7 times. The principle is to coat the surface of the structure that is easy to paint and leave the stainless-steel partsand componentunder the mud uncoated.

In order to reduceanode weight for a cathodic protected structure the majority component surface should be painted with high grade coating. Theuncoated buried parts and welding areashould be includedin uncoated surface area consideredfor CP design. Also,provide a higher breakdown factor forcomponents that have a high risk to coating damage during installation.

It is established in the study that coated structure lower the cost associated to anodes purchase and installation.Nevertheless,there is extra cost for the purchase of paint and application. These costs

were calculated and compared and presented in Table 6.0 for the jacket structure, mooring pile and crude pipeline respectively. The advantages of coated structures include protection area from anode is increase, easier to arrange anodes and weight reduction for structural members. However, one of thedisadvantages of structure surface coating is that it may be more difficult to handle components, extended project schedule and delay inproject completion.

Considering the technical facts presented in this study, it may be resolved that the appropriate solution to prevent structure from corrosion damage is a combinationof coating and cathodic protection, nevertheless this may not be always the most economical decision. The cost associated with the structure surface coating may be diverse depending on where thestructure is fabricated and assembled. Thus, an independent economic analysis is highly recommended for each project to

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determine the most economical between coated and uncoated with combination cathodic protection.

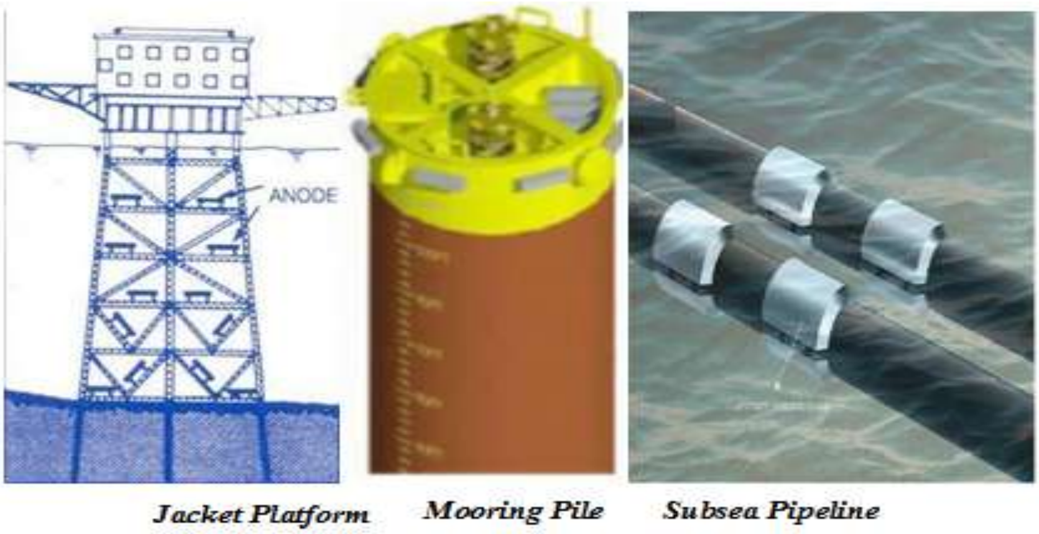

Fig 1.0: Combination of Coating and Cathodic Protected Structures

Table 1.0: Steel Area Calculations

Facility Description	Area (m^2)		
	0-30 m	30 m and down	Total
Jacket Structure			
Area in Splash Zone	456	0	456
Area in immersed seawater	1188	10344	11532
Area in mud zone	0	1602	1602
Uncoated Welding zones	220	745	965
Total	**1864**	**12691**	**14555**
FPSO Mooring Pile			
Surface In Sea water			
Head Plate	0	33.91	33.91
Lateral Anchor Shell	0	20.64	20.64
Lowering Padeye	0	2.20	2.2
Mooring Chain	0	24.66	24.66
Total	**0**	**81.41**	**81.41**
Surface in Mud			
Lateral Anchor Shell	0	412.8	412.8
Lowering Padeye	0	1.5	1.5
Moring Chain	0	16.44	16.44
Total	**0**	**430.74**	**430.74**
Crude Oil Pipeline			
Surface In Sea water			
Area in immersed seawater	0	0	0
Area buried on land	4241.70	0	4241.70
Total	**4241.70**	**0**	**4241.70**

Table 2.0: Anode Quantity Estimation by Mass based on AverageCurrentIntensity

S/N	Facility Conditions	Current Required (A)	Design Life (Year)	Comsumption Rate	Utilization Factor	Total Anode Weight (Kg)	Anode Unit Weight (Kg)	Anode Quantity by Mass
Jacket Structures								
1	Coated Structure	343.84	25	3.5	0.9	33429	217	154
2	Uncoated Structure	1461.76	25	3.5	0.9	142115	217	655
Mooring Suction Pile								
1	Coated Structure	11.55	25	4.38	0.8	1581	65	24
2	Uncoated Structure	20.11	25	4.38	0.8	2752	65	42
Crude Oil Pipeline								
1	Coated Pipeline	50.90	20	4.38	0.8	5574	27	206
2	Uncoated Pipeline	127.25	20	4.38	0.8	13934	27	516

Table 3.0: Final Check for Anode Current Drawing Capacity Vs Initial Polarizing Required Current

Facility Description	Condition Description	Anode Quantity	Anode Resitance at Initial Stage (ohm)	Initial polarizing required current (amps)	Current Drawing Capacity (amps)	10% Increase of Initial polarizing required current (amps)	Final Check $Id \geq 1.1 \times Ip$
Jacket Structure	Coated	154	0.060	107.21	641.87	117.93	Ok
Jacket Structure	Uncoated	655	0.060	1461.76	2728.79	1607.94	Ok
FPSO Mooring Pile	Coated	24	0.149	9.43	40.81	10.37	Ok
FPSO Mooring Pile	Uncoated	42	0.149	24.90	71.04	27.39	Ok
Crude Oil Pipeline	Coated	206	0.046	50.90	1121.90	55.99	Ok
Crude Oil Pipeline	Uncoated	516	0.046	127.25	2804.75	139.98	Ok

Ip - Initial polarizing required current, Id - Current Drawing Capacity

Table 4.0: Summary of CP Calculations for Coated Vs Uncoated

Facility Description	Coated Option			Uncoated Option			Ratio Uncoated Vs Coated
	Anode Wiegth (kg)	Anode Quantity	Total Anode Wight (kg)	Anode Wiegth (kg)	Anode Quantity	Total Anode Wight (kg)	
Jacket Structure	217	154	33429	217	655	142115	**4.3**
FPSO Mooring Pile	65	24	1581	65	42	2752	**1.7**
Crude Oil Pipeline	27	206	5,574	27	516	13934	**2.5**

Table 5.0: Cost Benefit Analysis for the Coatedand Uncoated Structure Surface

Facility Description	Condition Description	Anode Quantity	Anode Weight (kg)	Cost of Anode and Installation (kg/$)	Area Painted (m^2)	Cost of Paint and Application (m^2/$)	Total Anode Cost (USD)	Total Paint Cost (USD)	Total Anode and Paint Cost (USD)	Cost Benefit between Coated & Uncoated (USD)
Jacket Structure	Coated	154	217	1582	11988	45	243,706	539,460	783,166	**252,899**
Jacket Structure	Uncoated	655	217	1582	0	0	1,036,065	0	1,036,065	
FPSO Mooring Pile	Coated	24	65	974	81	45	23,689	3,663	27,353	**13,887**
FPSO Mooring Pile	Uncoated	42	65	974	0	0	41,240	0	41,240	
Crude Oil Pipeline	Coated	206	27	822	4242	45	169,685	190,877	360,561	**63,651**
Crude Oil Pipeline	Uncoated	516	27	822	0	0	424,212	0	424,212	

FPSO with Twelve (12) mooring pile (Cost saving 13,887 x 12 = $166,644)

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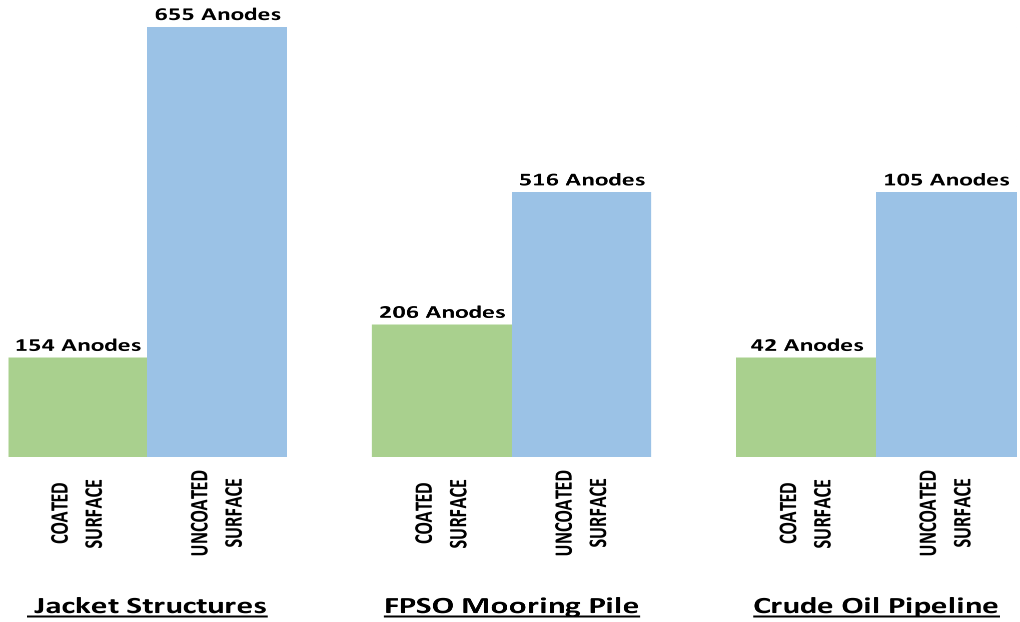

Fig 2.0:Number of Anodefor individual Structures

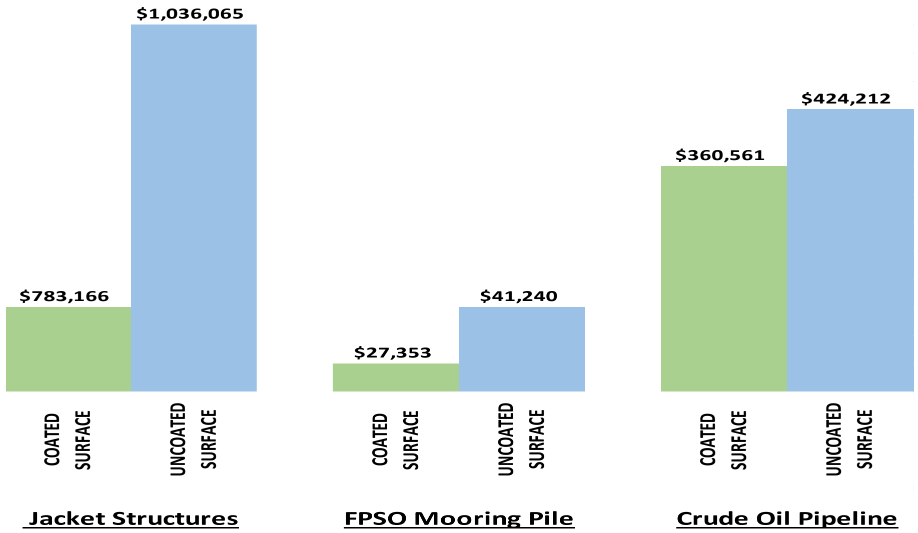

Fig 3.0:Cost of Cathodic Protection for individual Structures

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