

GENERAL SPECIFICATION

CORROSION

GS EP COR 002

Corrosion control on production facilities: Field operations

05	10/2012	Major changes and additions on the Corrosion Management strategy. Definition of the minimal content of the "Corrosion Management during Field operations" document.
04	01/2011	General review - Definition of the Corrosion Management document - Inclusion of a paragraph on the organisation of Corrosion management
03	10/2009	Reinforcement of Corrosion monitoring requirements. Biocide treatment specifications adjusted to their content in active components
02	10/2008	Additional tables: corrosion treatment of closed loop cooling water and hot water. Inclusion of specific pH stabilisation conditions for Sour TEG units. Requirement for a pluri-annual painting plan and a formal paint survey as part of the Painting maintenance Plan, in Appendix - Table 3.8
00	10/2005	First issue
Rev.	Date	Purpose of the revision

Owning entity: DEV/TEC	Managing entity: DEV/TEC/COR
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1. Scope

This document is related to Corrosion Control on Production Facilities. It is applicable to field operation activities, from production start-up to field abandonment (design and construction activities being covered in other specifications, based on the same corrosion control considerations).

This document specifies the main activities of Corrosion entities in charge of field operations in operating subsidiaries, based on a defined Corrosion Management strategy. It also specifies practical methodologies and requirements for:

- Performing internal corrosion assessments on operated facilities
- Defining corrosion mitigation and corrosion monitoring programs
- Applying these programs during normal field operations
- Running exceptional operations with no adverse corrosion impact.

Preliminary remarks: Due to the wide variety of parameters and solutions applicable to corrosion control, this document not only includes general specifications but also some indicative or applicative tables to be used within defined application limits. *Some comments and explanations are also given in italics, with no prescriptive value.*

2. Reference documents

The reference documents listed below form an integral part of this General Specification.

External Documents

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published at the effective date of this document.

Reference	Title
Not applicable	

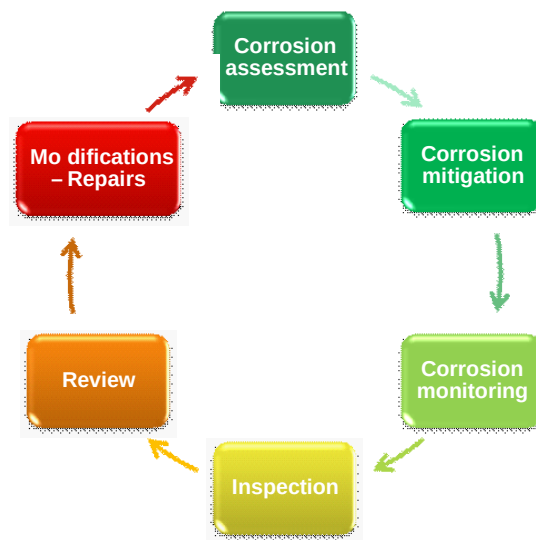
Total General Specifications

Unless otherwise stipulated, the applicable version of these documents, including relevant appendices and supplements, is the latest revision published in the applicable yearly collection.

Reference	Title
GS EP COR 001	Corrosion control on production facilities: Design and construction
GS EP COR 451	Corrosion and Coatings Integrity Inventory for Offshore Installations

3. Definitions

Corrosion management: The overall Corrosion Management process for any production facility is summarized in the following loop, which is applicable both during design and construction and during Production:



Preventive actions for corrosion mitigation, *i.e. all actions undertaken during operation to control the corrosion of susceptible materials and equipment* include, but shall not be limited to:

- Metallic and non-metallic material selection
- Chemical treatments dedicated to corrosion mitigation: Corrosion inhibition, biocide treatments, oxygen scavenging, chlorination, pH stabilisation
- Physical treatments applicable to corrosion mitigation: Dehydration, de-oxygenation, H₂S and/or CO₂ removal, operational pigging, etc.
- Cathodic protection
- Painting and coating
- Thermal insulation and fire-proofing materials, with respect to their potential impact on external corrosion.

Corrosion Monitoring activities, *i.e. all actions regularly undertaken to verify the implementation and efficiency of preventive actions* include, but shall not be limited to:

- Follow-up of chemicals injection rates
- Follow-up of Cathodic protection equipment
- Potential and current measurements for cathodic protection
- Coupons and corrosion probes
- Chemical analyses (inhibitor, iron, oxygen, pH)

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- Bacterial counts (kits, bioprobes, etc.)
- Hydrogen probes
- Ultra-sonic mats, Field signature Monitoring (FSM).

4. The "Corrosion management during field operations" document

It is the responsibility of the entity in charge of Corrosion Control of a subsidiary to put in place a corrosion management strategy and to formalize it in a "Corrosion management during field operations" document.

This document is the "mother document" specifying how corrosion is managed within the subsidiary throughout the production period. It defines the organization and the technical bases used to control corrosion on all facilities. It supports application documents which are established (per area and/or per assets/ facilities) to assure the proper implementation of the strategy. A minimal content of this document and an indicative list of application documents are given in appendix 1.

The next paragraphs define the main requirements related to this corrosion management during field operations, essentially on corrosion assessment, corrosion mitigation, corrosion monitoring and review tasks. Inspection and maintenance activities are not covered apart for their strict corrosion part as they are dealt with in other documents.

4.1 Organisation

The corrosion management document shall define, if not already done in an upper level document, the organisation in charge of corrosion control of the facilities during field operation:

- Tasks to be managed, i.e.:
 - Periodic corrosion assessment
 - Corrosion mitigation programs and implementation
 - Corrosion monitoring programs and implementation
 - Review of inspection programs and results, in close relationship with the inspection entity
 - Exceptional operations with a possible corrosion impact.
- Responsibilities, accountabilities, interfaces between entities in charge
- Human resources
- Qualification and training

4.2 Corrosion register

A formal Corrosion register shall be established and regularly up-dated.

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The Corrosion Register is generally a part of a wider "Plant Asset Register" managed by the Inspection entity. It contains the necessary information and documentation on all the equipment involved in corrosion management activities during field operations:

- Construction materials,
- Other mitigation solutions applied during the design and construction, with all necessary characteristics,
- All equipment available for chemicals' injection
- All equipment available for corrosion monitoring.

4.3 Corrosion assessment during operations

A Corrosion assessment shall be established and regularly up-dated to:

- 1. Evaluate the need for applying new preventive solutions or improving the solutions in place as well as to set the efficiency target of these solutions**
- 2. As part of any RBI evaluation for preparing inspection programs. *Corrosion Assessments are currently included in RBI evaluation tools.***

The corrosion assessment aims at evaluating whether corrosion is well controlled or not and at which rate it is likely to proceed, in case of insufficient control.

It shall be used for revising corrosion mitigation, corrosion monitoring, and inspection programs, and is a key input for the definition of planned maintenance & repairs.

The deliverables of this Corrosion Assessment are in two parts:

1. The Natural Corrosion Likelihood, i.e. without any applied mitigation: This Natural Corrosion Likelihood is particularly used to define whether additional mitigation solutions are needed or not and to evaluate how quick problems might be experienced if such mitigation was not applied or inefficient.
2. The final Corrosion Likelihood, which also accounts for:
 - The efficiency of preventive solutions used, if any
 - The corrosion monitoring and inspection results.
 - The last known or expected condition of the equipment considered (extent of corrosion damages if any, repairs, etc.)

Note: For new facilities, the Natural corrosion assessment during field operations is based on similar tools and methodologies as those used during design (cf. **GS EP COR 001**). The First Natural Corrosion Likelihood evaluation is the one elaborated within the Project phase.

Corrosion Assessments shall be regularly revised, and as a minimum in case of:

- Any significant change in operating conditions, such as but not limited to:
 - Start-up of a new field using existing facilities or equipment
 - Implementation of a new process unit which modifies the service conditions of existing facilities or equipment
 - A change in production rates by more than 50%.

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- Unexpected corrosion events likely to re-occur at other locations and not covered by existing corrosion assessment results,
- Corrosion monitoring results regularly in contradiction with the corrosion assessment.

4.4 Corrosion mitigation

A Corrosion Mitigation Program shall be established and regularly updated. This program shall specify all necessary actions to be undertaken during operational life to prevent corrosion failures of any important equipment before its expected end of service.

The bases of internal corrosion and its mitigation shall be defined in the "Corrosion Management document for all production and injection facilities.

"Corrosion Mitigation Programs" shall include all relevant solutions as described in § 3. A typical structure to be followed is shown in Appendix 2.

For any preventive action of the corrosion mitigation program, the following shall, as a minimum, be specified:

- The method to be used
- The location where it will be used
- The equipment to be used
- The requirements for use (dose rates, potential values, flow rates, etc.)
- The quantitative efficiency levels targets
- The relevant application procedures.

The corrosion mitigation program shall be formally delivered to all entities in charge of its implementation, together with all relevant procedures needed to allow its correct application.

The availability of the necessary material and human resources for the implementation of the corrosion mitigation program shall be verified.

The Corrosion mitigation program shall be updated regularly, and as a minimum:

- Every year
- For physical and chemical treatments: when production rates are changed by more than $\pm 25\%$, or new fields or new process facilities are added
- When corrosion monitoring results are regularly in contradiction with expectations, or quickly drifting from previous average values
- When inspection results are in contradiction with expectations, based on the supposed performance of preventive actions.

The bases for a typical corrosion mitigation program are given in Appendix 3 for:

- Table 3.1: Corrosion inhibition of oil and gas production facilities
- Table 3.2: Biocide treatment of oil and gas facilities

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- Table 3.3: pH stabilisation of MEG/DEG fluids used as hydrate inhibitors and for TEG dehydration units
- Table 3.4: Corrosion treatment of water injection facilities
- Table 3.5: Corrosion treatment of closed loop cooling water facilities
- Table 3.6: Corrosion treatment of pressurised hot water facilities
- Table 3.7: Operational pigging of pipelines for corrosion prevention (excluding intelligent pigging inspection)
- Table 3.8: Painting maintenance.

4.5 Corrosion monitoring

A corrosion monitoring program shall be established and regularly updated, aiming at either:

- 1. Verifying the effective use and the performance of preventive actions, if any,**
- 2. Verifying that corrosion likelihood remains below the maximal acceptable level, when no preventive action is deemed necessary.**

A formal corrosion monitoring program shall be established as a minimum for physical and chemical treatments, and for cathodic protection (internal and external).

Corrosion monitoring results shall be regularly gathered, analysed (on a monthly basis) and kept over the whole operational life time of the facilities considered.

Note: Corrosion monitoring is different from inspection. It aims at evaluating the performance of preventive actions within short time delays (days to months depending on the technique) but without any direct indication of the physical condition of the equipment considered. Inspection is focused on the corrosion status of equipment on a longer term basis (months to years).

The monitoring program shall cover all relevant production and injection facilities. A typical list of monitoring techniques is given in Appendix 4, Table 4.1.

Among the various preventive actions undertaken, corrosion monitoring activities will be focused on cathodic protection and physical and chemical treatments, whereas painting-coating and corrosion resistant materials are mostly covered by Inspection programs.

The Corrosion Monitoring program is a formal document defining all activities and measurements to be handled to cover the objectives listed here above.

For each measurement/ activity the following shall be included, as a minimum:

- The monitoring technique used
- The location where it is used
- The relevant application procedure
- The measurement frequency
- The entity in charge of the activity,

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- The threshold acceptance values.
- The actions to be undertaken when threshold values are exceeded,

All application procedures necessary to the satisfactory application of the corrosion monitoring program must also be made available to the entities in charge.

The Corrosion monitoring program is regularly up-dated, as a minimum when:

- New facilities are installed or existing facilities are closed,
- Process modifications are made, which may modify the corrosiveness of the fluids which are monitored or the efficiency of the applied mitigation,
- Changes are made on the applied mitigation programs,
- Corrosion monitoring or inspection results are regularly in contradiction with expectations,

As long as chemicals treatments are concerned, the corrosion monitoring program shall include:

- The verification of injection specifications (flow rates, dose rates, continuity or frequency and duration), based on typical guidelines indicated in Appendix 4, Table 4.2
- Indicative parameters related to treatments' efficiency, as per reference documents (coupons, probes, titrations, bacterial counts, etc.). A sound corrosion monitoring program requires combining several monitoring techniques in parallel.

4.6 Inspection activities related to corrosion control

The corrosion entity in charge shall

- **Maintain a permanent and close relationship with the inspection department, with systematic and mutual exchange of information on significant corrosion events experienced, inspection results involving corrosion damages, poor corrosion monitoring results, etc.**
- **Be involved in the definition of RBI type inspection programs for the Corrosion Likelihood evaluation of the concerned equipment.**

Be involved in the implementation of inspection programs where corrosion is the essential reason for inspection, particularly when the objective of the inspection is to establish the painting maintenance program.

For RBI programs, the Corrosion entity is in charge of validating the Corrosion Likelihood evaluation used in the RBI tool. This evaluation shall be consistent with the Corrosion Assessment defined in § 4.3.

The Corrosion entity shall check that the planned inspection programs are adequate with respect to corrosion assessment and corrosion threats, and consistent with any additional information regarding corrosion events, corrosion monitoring results, etc.

Inspection results shall be reviewed with respect to their possible impact on any other equipment potentially subjected to similar corrosion damages.

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Inspection results shall be analysed in view of adjusting, if necessary, corrosion mitigation and monitoring programs, particularly when unpredicted corrosion damages are detected by inspection.

The Corrosion entity is directly involved in Painting Maintenance activities, as detailed in Appendix 3:

1. Definition of the Painting maintenance strategy, as part of the Corrosion Management strategy,
2. Performance of "Corrosion and Coating Integrity Inventories" as per **GS EP COR 451**,
3. Definition of pluri-annual painting programs
4. Qualification of contractors,
5. Checking, inspection and acceptance of painting works

4.7 Corrosion impact of exceptional operations

A detailed review of exceptional operations likely to have a detrimental corrosion impact on production facilities shall be carried out.

The necessary mitigation actions needed to minimize the corrosion impact shall be defined in close relationship with the entity in charge of the operation. This shall be carried out within a timeframe which guarantees the practical implementation of these mitigation actions during the operation, and with consideration to operational limitations and constraints.

An indicative list of operations requiring to be reviewed is given in Appendix 5.

4.8 Review – Reporting – Filing

Mitigation and monitoring results shall be gathered through a formal corrosion monitoring system which shall include:

- The collection of monitoring data from all sources
- The regular analysis of results
- The review of alarms and results exceeding threshold values.
- The calculation of key performance indicators (KPI)

Mitigation and monitoring data shall be archived throughout the whole service life of the relevant facilities.

A periodic report shall be issued. This report shall include:

- What has been implemented on corrosion mitigation,
- The main monitoring results, with a particular emphasis on results exceeding threshold levels,
- KPIs,



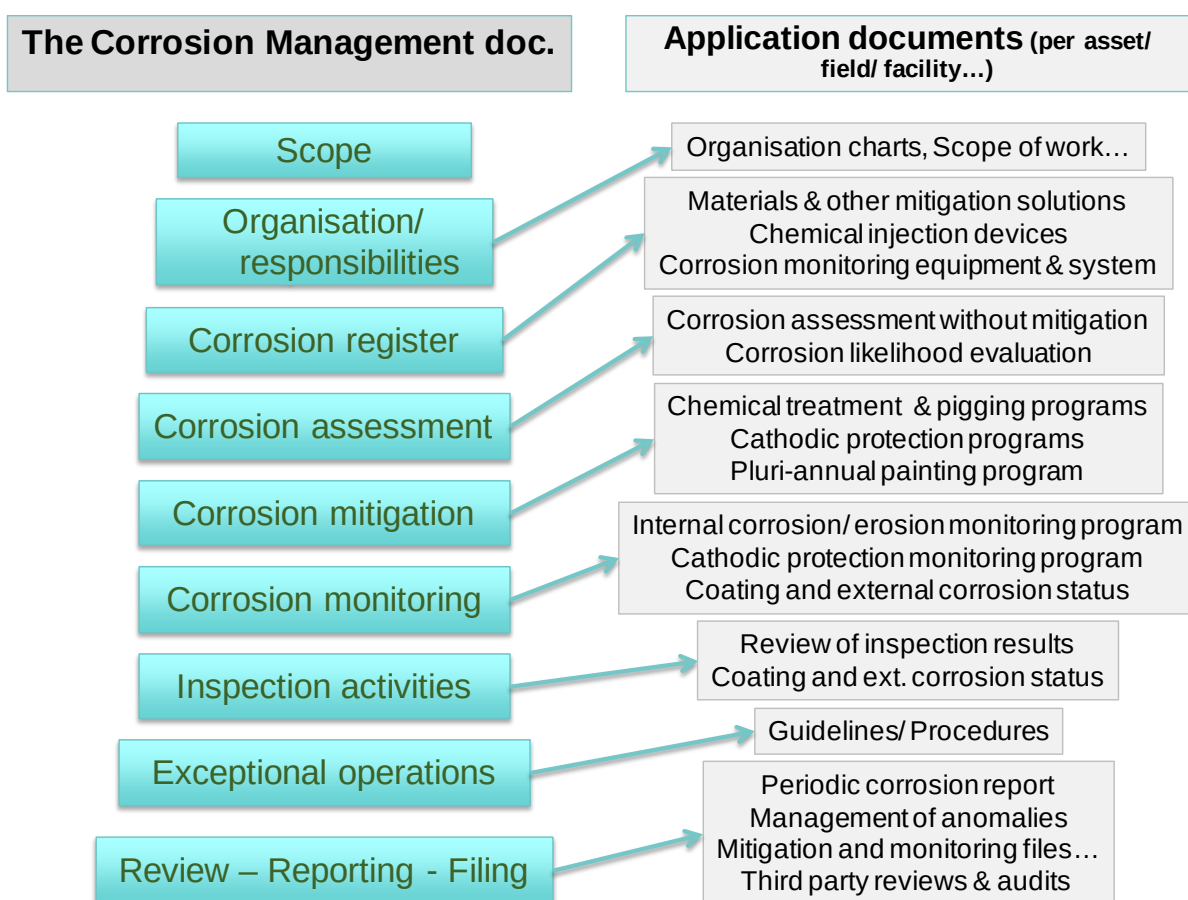
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- Inspection results of key consequence for corrosion control,
- A list of anomalies and a follow-up of corrective actions, if any.

The most important results shall be reported on a graphical basis versus time (*usually over a one year sliding period of time*).

Appendix 1 Tentative structure of the Corrosion Management document and associated application documents

This appendix defines the minimal content of the "Corrosion Management during Field Operations" document of a production subsidiary and a possible list of associated application documents (programs, procedures, methodologies, etc.). This list is not exhaustive. Depending on the size of the subsidiary, a number of additional documents can be added.



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Appendix 2

Appendix 2 Typical structure of "Corrosion Mitigation Programs"

* Preventive solutions usually implemented at design/construction stages and not requiring any more activity during operation are indicated in italics.

System...	...generally including:	Typical preventive methods*
Physical and chemical treatments		
Production wells	Tubing, well-head, flowline	<i>CRAs</i> Rarely corrosion inhibition
Crude oil and gas trunklines	Risers and pipelines, receiving separators	Corrosion inhibition, biocides, operational pigging, pH stabilisation
Liquid lines downstream crude separation process	Water and liquid lines, water disposal facilities, crude dehydration and stabilisation	Sometimes, top up of corrosion inhibitor and/or biocides
Water injection network	Topside piping, flowlines, risers and pipelines, wells	Filtration, Physical and chemical de-aeration, biocide treatment, corrosion inhibitors
Wet gas compression process	Topside piping, exchangers, water knock out drums, compressors	<i>CRAs</i>
Glycol dehydration process	Contactor, regenerator, exchangers, topside piping	<i>CRAs</i> , pH control
Gas-lift or gas injection network	Topside piping, gas-lift pipelines and flowlines, wells	Inhibitors or <i>CRAs</i> if wet condensing gas. Nothing if dry gas
Utilities: Cooling water network	Piping, exchangers, vessels, surge tanks	Multi-functional inhibitors (O ₂ scavenger, pH control, protective scaling, dispersant) + biocide, N ₂ or fuel gas blanketing of surge tanks
Utilities: Pressurised hot water network	Piping, exchangers, vessels, boilers, surge tanks	Multi-functional inhibitors (O ₂ scavenger, pH control, protective scaling, dispersant) + biocide, N ₂ or fuel gas blanketing of surge tanks
External cathodic protection (CP)		
Offshore structures (immersed or buried)	Jackets, FPSO, subsea modules, anchors	CP with sacrificial anodes, rarely impressed current
Immersed or buried pipelines	Risers, pipelines, subsea modules and valves	CP with sacrificial anodes, rarely impressed current

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Appendix 2

System...	...generally including:	Typical preventive methods*
Storage tank floors	Side of the floor in contact with the soil	CP with sacrificial anodes or impressed current + <i>painting</i> + <i>soil preparation</i>
Internal Cathodic Protection		
Pressure vessels	Separators, water injection and utility vessels	Sacrificial anodes
Tanks	Onshore storage tanks, FSO/ FPSO storage tanks, ballasts, slop tanks, etc.	Sacrificial anodes
Painting and coating		
Pipelines	External surface	<i>3 layers PE or PP, occasionally FBE or tar enamel</i>
	Internal surface	<i>Occasionally internal epoxy coatings</i>
Immersed structures	Jackets (buried part or splash zone)	<i>Painting</i>
	Subsea facilities (templates, Xtrees, manifolds, etc.)	<i>Painting. No maintenance</i>
	Hull of FSU, FPSO, etc.	<i>Painting. No maintenance for the immersed surfaces</i>
Aerial structures and facilities	Structural elements, piping, vessels, tanks, valves, etc.	<i>Painting. Passive Fire Protection in some areas. Periodic maintenance</i>
	Internal surface of tanks (storage, ballast, slop) and vessels	<i>Internal coating. Occasionally some local repairs but no extensive maintenance</i>

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Appendix 3 Typical Corrosion Mitigation Programs

Table 3.1: Typical corrosion inhibitor treatments for oil and gas production facilities

Table 3.2: Typical biocide treatments for oil and gas production facilities

Table 3.3: Typical pH stabilisation treatments for gas production facilities

Table 3.4: Anticorrosion treatment of water injection facilities

Table 3.5: Anticorrosion treatment of closed loop cooling water facilities

Table 3.6: Anticorrosion treatment of pressurised hot water facilities

Table 3.7: Typical guidelines for operational pipeline pigging for corrosion purpose

Table 3.8: Typical guidelines for definition of paint maintenance programs

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Appendix 3

Table 3.1: Typical corrosion inhibitor treatments for oil and gas production facilities

Facility	Typical service conditions	Typical chemicals	Injection mode	Typical dosage	Frequency/ duration	Target monitoring values	Comments
Corrosion inhibition							
Gas wells with no downhole injection facilities		"Oil-soluble" inhibitors	Batch	Diluted to 5 to 20% diluted with diesel or condensate	1 to 2 months	> 10 ppm in produced water	Unusual mode of treatment, limited to corroded wells not equipped for any other type of inhibition
Oil-water lines Oil wells equipped with down-hole injection devices	T < 50°C 50 ≤ T < 80°C 90 ≤ T < 110°C T ≥ 110°C	"Water-soluble" film forming inhibitors	Continuous	20 ppm/Water 50 ppm/Water 100 ppm/Water 150-200 ppm/Water	Continuous	4 mpy	Typical dose rates are given for BSW ≥ 50%. Half of the specified dosage vs Oil + Water to be specified up to 50% BSW These dose rates also apply to 3 phase lines with oil and water as main fluids
Crude gas-condensate lines Gas wells equipped with downhole injection devices	T < 50°C 50 ≤ T < 80°C 90 ≤ T < 110°C T ≥ 110°C	"Water-soluble" film forming inhibitors	Continuous	10 L/M ³ Gas 15 L/M ³ Gas 20 L/M ³ Gas 30 L/M ³ Gas	Continuous	4 mpy	Values considered for moderate liquid flow rates, below 200 - 300 m ³ /MMSm ³ . Inhibitor concentration to be also consistent with concentrations here above vs Water or Oil + Water
Wet gas line with residual water content (e.g. downstream compressors)	T < 50°C	"Water-soluble" film forming inhibitors	Batch	1000 ppm/total condensing water reached with 2 injections maximum	1 week with injection time < 1 hr		Treatment designed for making available inhibitor at low points where condensed water is likely to accumulate

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Appendix 3

Table 3.2: Typical biocide treatments for oil and gas production facilities

Facility	Typical service conditions	Typical chemicals	Injection mode	Typical dosage *	Periodicity/ duration	Target monitoring values	Comments
Biocide treatments							
Oil-water lines. Gas/ condensate lines with low flow velocities (stratified, liquid velocity < 2 m/s)		Mixtures of Glutaraldehyde, Quaternary ammonium, THPS, etc.	Batch	400 to 500 ppm/Water	1 week/ 5 hrs	> 100 bact/ cm ³ and < 100 bact/ cm ² (bioprobe monitoring)	Alternate 2 products, with distinct chemistry (change each month) Periodicity and dose rate to be adjusted depending on monitoring results
Any line	Short duration pressure testing	Quaternary ammonium biocide + O ₂ scavenger or multi-purpose dedicated chemical	100% of the water volume	300 ppm biocide + 100 to 200 ppm O ₂ scav., or 500 ppm multipurpose chemical	Permanent		O ₂ scavenger optional if fluid flushed within 1 week O ₂ scavenger as per Supplier's documentation + 20%
Any line	Long term cocooning of already used lines	Quaternary ammonium biocide + O ₂ scavenger or multi-purpose dedicated chemical	100% of the water volume	500 ppm biocide + 100 to 200 ppm O ₂ scav., or 1000 ppm multipurpose chemical	Permanent		O ₂ scavenger as per Supplier's documentation + 20% Slight Nitrogen over-pressure + pressure follow-up, to prevent and monitor oxygen entries

* Biocide dosages given in this table refer to the commercial product itself, considering that it contains 50 ± 5% of active biocide components. Dosages/injection rates have to be increased/ decreased accordingly if biocides with lower/ higher contents in active components are provided.

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Appendix 3

Table 3.3: Typical pH stabilisation treatments of glycol used on gas production facilities

Facility	Typical service conditions	Typical chemicals	Injection mode	Typical dosage	Periodicity/ duration	Target monitoring values	Comments
pH stabilisation							
Gas-condensate lines with permanent glycol injection	Sweet conditions (%H ₂ S < %CO ₂ /1000)	MDEA, KOH, NaOH, etc.	Initial + periodic additions in case of pH decrease	Calculated to reach an in situ pH of 6.5	Occasional top-up depending on pH decrease and glycol top-up	In situ pH of rich DEG ≥ 6.5 at line outlet	Dose rate dependent on pressure and CO ₂ content (Typically 0.02 to 0.2 m/L in rich glycol = 0.3 to 3% vol in lean glycol). Calculated with dedicated tools by TEC/COR.
Gas-condensate lines with permanent glycol injection	Sour conditions	MDEA, KOH, NaOH, etc.	Initial + periodic additions in case of pH decrease	Calculated to reach an in situ pH of ≥ 7.0	Occasional top-up depending on pH decrease and glycol top-up	In situ pH of rich DEG ≥ 7.0 at line outlet	Same as above for dose rate calculation (Typically 0.1 to 0.5 m/L in rich glycol = 1.5 to 7.5% vol in lean glycol)
Sweet TEG dehydration units (H₂S < 100 ppm vol)	TEG closed circuit. Water content from 0.1 to 5% in TEG	MDEA.	Initial + periodic additions in case of pH decrease	Calculated to reach an in situ pH of 6.8	Occasional top-up depending on pH decrease and glycol top-up	In situ pH of rich TEG ≥ 6.5	Same as above for dose rates calculation (Typically 0.02 to 0.2 m/L in rich glycol = 0.2 to 2% vol in lean glycol)
Sour TEG dehydration units (H₂S ≥ 100 ppm vol)	TEG closed circuit. Water content from 0.1 to 5% in TEG	MBTNa, MDEA	Initial + periodic additions in case of pH decrease	Necessary amount to assure pH within 7.5 to 8 in the lean TEG	Occasional top-up depending on pH decrease and glycol top-up	Lean TEG pH > 7.5	

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Appendix 3

Table 3.4: Corrosion treatment of water injection facilities

Injection point	Typical service conditions	Typical chemicals	Injection mode	Typical dosage	Periodicity/ duration	Target monitoring values	Comments
Chlorination							
Upstream seawater lift pumps	Raw seawater	Hypochlorite	Continuous	1 to 5 ppm/Water, depending on organic content	Continuous	0.7 ppm at inlet of the stripping tower	Not only important for fouling control, but also to prevent bacterial growth in filters
Deaeration							
Deaeration unit	Physical de-aeration	Gas or vacuum stripping	Permanent	Gas Water Ratio ~1.4 to 1.5 for gas stripping	Permanent	30 to 200 ppb O ₂	30 to 200 ppb to be attained with no addition of O ₂ scavenger. Higher values indicate a poor performance of the stripping tower.
Center of the stripping tower, above upper water level	Chemical de-aeration	Bisulfite	Continuous	0 to 10 ppm/Water when physical deaeration is OK	Continuous	10 to 30 ppb O ₂	Residual O ₂ within 10 to 20 ppb is preferable to O ₂ below detection limits (< 5 to 10 ppb)

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Appendix 3

Injection point	Typical service conditions	Typical chemicals	Injection mode	Typical dosage	Periodicity/ duration	Target monitoring values	Comments
Biocide treatments *							
Stripping tower outlet	Bacterial control	Different mixtures of Glut, Quats, THPS, etc.	Batch	350 to 500 ppm/Water	1 week/ 5 hrs	< 100 bact/cm ³ and < 100 bact/cm ² on bioprobes	Alternate 2 products, with distinct chemistry (change each month) Periodicity and dosage to be adjusted depending on monitoring results
Stripping tower outlet	Reservoir souring to be prevented	Different mixtures of Glut, Quats, THPS, etc.	Continuous	20 ppm/Water	During 3 months after injection start-up	< 100 bact/cm ³ and < 100 bact/cm ² on bioprobes	Initial treatment to be applied only when reservoir souring is expected
Inhibitor treatment							
Stripping tower outlet	Corrosion control	"Water-soluble" film forming inhibitors	Continuous	10-15 ppm/Water		< 4 mpy	Only if gas stripping process uses a gas containing more than 0.1% CO ₂

* Same remark as for Table 3.2 for biocide dosage.



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Appendix 3

Table 3.5: Corrosion Treatment of closed loop cooling water facilities

Typical make up water quality: Total Hardness < 10 mg/L (as CaCO₃)
[Cl⁻] < 100 mg/L
TDS < 250 mg/L

Typical service conditions: T < 55°C
Closed loop

Two options of water treatment are presented in the tables below.

Treatment no. 1

(System is completely closed, no contact with atmospheric media, pressurised system with nitrogen only)

Typical conditioning product	Role	Injection mode	Typical dosage	Periodicity	Target monitoring values	Comments
Phosphate	pH control	Initial + top up in case of pH decrease	Calculated to reach an in situ pH > 9.5	Batch	pH > 9.5	No copper materials
Sulfite	O ₂ scavenger	Initial + periodic additions in case of [SO ₃ ²⁻] decrease	Calculated to reach an in situ sulfite concentration > 10 mg/L	Batch	[SO ₃ ²⁻] > 10 mg/L	System completely closed. No oxygen entrance
THPS based formulation	Biocide	Initial + periodic additions	Calculated to reach an in situ biocide concentration: 50 mg/L	6 months	BSR < 100 col/mL	Monitoring using water sampling & test kits

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Treatment no. 2

(System is completely closed, no contact with atmospheric media, pressurised system with nitrogen or fuel gas)

Typical conditioning product	Role	Injection mode	Typical dosage	Periodicity	Target monitoring values	Comments
Molybdate	Corrosion inhibitor	Initial + periodic additions in case of $[\text{MoO}_4^{2-}]$ decrease	Calculated to reach an in situ molybdate concentration $> 45 \text{ mg/L}$	Batch	$[\text{Mo}^{6+}] > 45 \text{ mg/L}$	$\text{pH} > 7.5$
Nitrite	Corrosion inhibitor	Initial + periodic additions in case of $[\text{NO}_3^-]$ decrease	Calculated to reach an in situ nitrite concentration $> 330 \text{ mg/L}$	Batch	$[\text{NO}_2^-] > 330 \text{ mg/L}$	Toxic for the environment
Azole (Benzotriazole or Tolyltriazole) Only if copper materials are present	Copper Corrosion inhibitor	Initial + periodic additions in case of azole decrease	Calculated to reach an in situ azole residual concentration $> 1.5 \text{ mg/L}$	Batch Or can be combined with Nitrite (multifunctional product)	Azole residual $> 1.5 \text{ mg/l}$	Only if copper and copper alloys are present into the system
Isothiazoline based formulation	Biocide	Initial + top up	Calculated to reach an in situ biocide concentration of 200 mg/L	3 months	No evidence of bio-organism	



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Table 3.6: Corrosion Treatment of pressurised hot water facilities

Typical make up water quality: Total Hardness < 10 mg/L (as CaCO₃)
 [Cl⁻] < 25 ppm
 TDS < 250 mg/L

Typical service conditions: T < 150°C
 Closed loop

Pressure gas: nitrogen (O₂: 0.5-2%)

Typical conditioning product	Role	Injection mode	Typical dosage	Periodicity	Target monitoring values	Comments
Phosphate	pH control	Initial + top up in case of pH decrease	Calculated to reach an in situ pH > 9.5	Batch	pH > 9.5	No copper alloys
Sulfite	O ₂ scavenger	Initial + top up in case of [SO ₃ ²⁻] decrease	Calculated to reach an in situ excess sulfite concentration > 10 mg/L	Batch	[SO ₃ ²⁻] > 10 mg/L	

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Table 3.7: Typical guidelines for pipeline operational pigging for corrosion control

Objective	Pipelines involved	Additional conditions	Type of pigs to be used	Typical/ max. periodicity	Comments
Biofilm/ bacterial cleaning of pipe wall	Water and oil/ water pipelines, 3 phase pipelines with low velocity (< 3 m/s total velocity)	Suspected or detected bacterial activity	Hard plastic plate pigs	1/2 weeks	No metallic abrasive brush pigs Pig to be launched before the periodic biocide injection
Remove water accumulating at low points	Commercial oil pipelines	Flow velocity < 2 m/s	Foam or disk pigs	1/3 months	
	Gas pipelines downstream compression, without complete deaeration	Flow velocity < 10 m/s	Id.	2/4 weeks	
	Gas pipelines downstream a undersized deaeration process	Flow velocity < 10 m/s	Id.	1/3 months	
Prevent solid particles accumulation	Oil/ water or 3 phase pipelines with low flow velocity	Identified sand production upstream the pipeline	Hard plastic disk pigs	Depends on the rate of solid accumulation, based on assessment and quantities of solids recovered during operational pigging	Each batch of sand collected should be weighed and logged Sand size and sizes distribution to be measured on sand breakthrough

Note: Indications in this table only refer to pigging made for corrosion purpose, not involving additional operational needs (e.g. wax removal).

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Table 3.8: Typical guidelines for paint maintenance

Objectives of painting maintenance

1. To maintain painted surfaces in such a condition that prevents integrity losses likely to have Safety, Environmental or Production impacts due to loss of confinement or to induce costly repairs. **On a practical point of view, a cost-effective painting maintenance should guarantee that any visible rusted or disbonded paint surface painting is repaired within 1 year, in order to prevent not only losses of confinement but also expensive repairs/ replacements of the item prior to painting.**
2. To apply an immediate protection by painting on any newly installed facility (if not supplied fully painted) and on all surfaces subjected to on site repairs, welding, physical or chemical damages.

General methodologies

Painting maintenance is performed by a combination of:

- Punctual major painting campaigns. Such planned operations require large means for scaffolding, surface preparation and paint application, and the necessary hosting capacities must be mobilized accordingly. These operations must be designed for painting at the same time all surfaces of the facility involved (process, utilities and structural surfaces).
- Short painting campaigns dedicated to a well defined and limited scope and attributed to a specific team.
- Long term daily painting maintenance with light teams hosted on site (continuous touch up repairs).

The adequate balance between these different solutions is dependent on the existing painting status of the facilities considered, as well as on climate and hosting conditions. As such this balance must be defined by each affiliate. Nevertheless, the following key rules must systematically be applied.

Key rules for paint maintenance

- An overall pluri-annual Painting Maintenance Plan must be established and regularly up-dated.
- This Painting Maintenance Plan must be based on a formal and regularly up-dated survey of "Corrosion and Coating Integrity Inventories" as per **GS EP COR 451**.



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- Surface preparation and paint application are key factors for the long term performance of the system applied. As such and whatever organisation is used, painting is made in accordance with Company's General Specifications.
- The Corrosion entity is responsible, as a minimum, for the definition of the surfaces to be maintained, the applicable specifications, the Quality Control and final reception of work. The Corrosion entity is also involved in the selection and periodic evaluation/auditing of the Contractor.
- As long as continuous touch up repairs are used, a close on site follow-up of painting teams is mandatory, through a dedicated technical contact in charge of the definition and the reception of the work.
- The continuous touch up strategy can be adequate for maintaining in good condition a facility not yet significantly damaged. On another hand experience has proven that it is not adapted to refurbish a significantly damaged facility, neither can it replace nor avoid implementing larger operations on surfaces with difficult access.

Particular attention must be given to the planning of painting activities in accordance with other maintenance and production activities. Hosting capacities as well as logistics must also be adapted to these painting activities.

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Appendix 4 Corrosion monitoring

Table 4.1: Typical list of corrosion monitoring techniques

Objective	Monitoring techniques	Comments
Physical and chemical treatments		
Verification of injection rates	Instantaneous injection rate measurement (manual or automatic) Daily level control of tanks Weekly measurement of stock + supply on each injection unit Monthly control of delivered quantities (global evaluation per field or site/ platform)	At least 2 different techniques, with 2 distinct times scales (day - week - month)
Verification of chemicals dose rates	Dosage of active chemicals (inhibitor, pH, alkalinity, phosphates, etc.) Dosage of reaction products (residual O ₂ , residual chlorine, pH, residual sulfite, etc.)	Periodicity: ~ monthly O ₂ and Chlorine on water injection: daily Residual sulfite, O ₂ in closed circuits: monthly
Verification of physical treatments	Water dew point on dry gas CO ₂ - H ₂ S content downstream gas removal units Efficiency of vacuum stripping towers for water de-aeration	Measure residual O ₂ content before and after closing O ₂ scavenger injection (15 to 20 minutes duration). Typical periodicity 3 months
Treatment efficiency	Corrosion coupons Electrical resistance probes (ER) Linear Polarisation Resistance (LPR), high sensitivity ER probes Dosage of iron content	Long term average Corrosion Rate (usually 6 monthly) Weekly to monthly Instantaneous to daily Weekly to monthly

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Objective	Monitoring techniques	Comments
Mixed inspection- monitoring tools	External permanent US monitoring with Fleximats Field Signature Monitoring (FSM)	1 to 3 months periodicity. Limited sensitivity for low corrosion rates Only if specified by TEC/COR
Bacterial monitoring	Water sampling + bacterial counts with Test-kits Bioprobes	Planktonic bacteria contained in the water volume. Typically weekly "Sessile" bacteria, on the metal surface. Monthly In both cases, Laberge test kits are strongly recommended
Polymer ageing (e.g. flexible lines)	Polymer coupons	1 set of coupons retrieved and replaced after 1 year, then retrieval and replacement every 2 years
External Cathodic protection (CP)		
Verification of rectifiers	Output potential & current, anode resistance	Weekly, preferably automatic
Efficiency of cathodic protection, offshore structures and pipelines (protected by sacrificial anodes)	Potential surveys Anode consumption	6 monthly to yearly on structures, 1 to 5 yearly on pipelines, depending on experience. 5 yearly (subsea inspections)
Efficiency of cathodic protection, onshore pipelines and structures (protected by impressed current)	Potential surveys (ON), verification of insulating joints (ΔV or by-pass current) Potential surveys (ON/OFF)	6 monthly Yearly
Internal Cathodic Protection		
Pressure vessels and tanks	Internal potentials Anode consumption	6 monthly to yearly, if internal ref. electrodes available 3 to 5 yrs, during internal inspection

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Table 4.2: Typical guidelines for chemicals' injection monitoring

Objectives of injection monitoring

1. Check that chemicals are injected according to specifications with respect to injection mode and dose rate.
2. Improve injection reliability in case of inadequate injection.

General methodologies

Chemicals injection must be monitored through a combination of the following methods:

- Daily (or at each site visit if less than daily): verification of the injection flow rate either through:
 - The measurement of the instantaneous flow rate, on a volumetric cell or on a dedicated flow meter if any
 - The measurement of the average daily flow rate by level change on the storage tank, if equipped for such measurement.
- Weekly: Average consumption determined by weekly measurement of stocks + supply on each injection unit.
- 3 months to yearly: Overall comparison of consumption versus specifications for each chemical during the period with the specified injection, over the whole asset (no detailed analysis per injection device).

Key rules

A few practical rules must be followed for a successful application of chemical treatments:

- Injection facilities must be regularly maintained and verified. In particular, instantaneous injection rates must be easily measurable
- Operators must be made aware of the objectives and importance of chemical treatments, and they must be given clear and up-dated injection specifications
- Operators must be fully involved in the application and monitoring of these treatments, and informed of all monitoring results associated with these treatments.

Periodic site visits of the Corrosion Control representatives must be partly devoted to a review of treatment application and to the verification of injection devices.

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Appendix 5

Appendix 5 Typical list of exceptional operations with expected corrosion impact

Operation	Facilities involved	Corrosion concern	Comments
Drilling rig connection to an offshore platform	Immersed structure	Satisfactory cathodic protection of the rig? If not, anode depletion on the Platform to protect the rig	Function of size of the drilling rig and duration of operation
Well acidification	Tubing, bottom hole liner and well equipment	Corrosion inhibitor adapted to all materials	A particular corrosion risk on stainless steel components (13% Cr, Duplex, etc.) if acid inhibitor not designed for SS
Production start-up after well acidification	Production facilities	What to do with initial acid returns?	No acidic fluid returns in production facilities below pH 3 allowed
Operation on well annuli	Casing and tubing	Prevent oxygen entries	A particular concern with Stainless Steel tubing
Injectivity tests	Tubing	Use de-aerated water	A particular concern with 13% Cr tubing
Periodic work-overs	Production facilities	Corrosion of carbon steels and SS	Use a de-aerated and biocide treated completion brine
Prolonged shut-down without cocooning	Pipelines, production topsides	Bacterial activity and risks of air entrance	Biocide treatments prior to shut-down. Slight over-pressure to be maintained
Long term cocooning	Pipelines, production plants, tanks, etc.	Bacterial activity and risks of air entrance	Water with biocide + oxygen scavenger or dry nitrogen atmosphere + overpressure
Pressure testing	Piping and vessels, pipelines	Bacterial pollution	Water with biocide or biocide + oxygen scavenger, depending on duration