PETROBRAS	TECHNICAL SPECIFICATION	Nº: I-ET-3010.2D-1200-940-P4X-001	
	CLIENT: AGUP		SHEET: 1 of 17
	JOB: HIGH CAPACITY FPSO - GAS EXPORTATION ALL ELECTRIC		
	AREA: ATAPU 2 AND SÉPIA 2		
SRGE	TITLE: **MATERIAL SELECTION PHILOSOPHY FOR DETAILED DESIGN**		INTERNAL
			ESUP

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SUMMARY

1. OBJECTIVE

This technical specification specifies requirements and gives recommendations covering materials selection for ATAPU 2 AND SEPIA 2 HIGH CAPACITY FPSO - GAS EXPORTATION ALL ELECTRIC. The requirements herein listed are applicable for all equipment and all piping systems (lines) within the Unit, including those within packaged systems (skidded packages and/or modules).

This document includes material selection for OD tubing and its connectors, when used either for instrumentation or for piping. This document does not set forth requirements for structural steel selection for offshore platforms hull or superstructures.

The rules herein listed are applicable for all stages of Engineering Development of the Unit (from Basic Engineering Design until the Detailed Engineering Design).

This document presents general requirements for the application of standard ISO 15156 (Materials for Use in H_2S-containing Environments in Oil and Gas Production) for the equipment and piping.

New equipment and new lines that originate from the Detailed Engineering Design phase of the Unit design (as SELLER's contractual scope of work) shall have its materials selected by SELLER in conformance with the rules herein listed.

Changes in the design condition (e.g., temperature, pressure, fluid, contaminants) for equipment and lines that may happen as a consequence of the Detailing Engineering Phase of the Unit (as SELLER's contractual scope of work) shall implicate in a reassessment by SELLER of the material selection previously performed, and this shall follow the rules herein listed as well.

2. NORMATIVE REFERENCES

All equipment shall comply with the requirements of this technical specification and references stated below. All equipment parts and details not complying with any of these requirements shall be informed on a "Deviation List". Otherwise, they will be considered as "Agreed", and so required.

2.1. CODES AND STANDARDS

The following codes and standards include provisions which, through reference in this text, constitute provisions of this specification. The latest issue of the references shall be used unless otherwise agreed.

- API 610	- Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries;
- ASME BPVC SEC II	- Material Specifications
- ASME BPVC SEC VIII	- Rules for Construction of Pressure Vessels
- ASME B31.3	- Process Piping
- ASME B73.1	- Specification for Horizontal End Suction Centrifugal Pumps for Chemical Process
- ASTM A578	- Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications
- ISO 21457	- Petroleum, petrochemical and natural gas industries — Materials selection and corrosion control for oil and gas production systems
- ISO 15156	- Petroleum and Natural Gas Industries – Materials for use in H_2S Containing Environments in Oil and Gas Production

2.2. REFERENCE DOCUMENTS

I-ET-3010.00-1200-940-P4X-002	GENERAL TECHNICAL TERMS
I-ET-3010.00-1200-500-P4X-001	NON METALLIC TANKS AND PRESSURE VESSELS DESIGN
I-ET-3010.00-1200-955-P4X-001	WELDING
I-ET-3010.00-1200-956-P4X-002	GENERAL PAINTING
I-ET-3010.00-1200-751-P4X-001	ANODES SPECIFICATION FOR MECHANICAL EQUIPMENT
I-ET-3010.00-1200-940-P4X-001	POLYMERIC MATERIAL FOR CRITICAL GAS SYSTEMS
I-ET-3010.00-1200-900-P4X-001	ADDITIONAL REQUIREMENTS FOR SOUR SERVICE 3.5% NICKEL STEEL
I-ET-3010.2E-1200-200-P4X-001	PIPING SPECIFICATION FOR HULL
I-ET-3010.2D-1200-200-P4X-001	PIPING SPECIFICATION FOR TOPSIDE
I-ET-3010.00-1200-498-P4X-002	ELECTRIC PROCESS HEATERS

2.3. CONFLICTING REQUIREMENTS

In case of conflicting requirements between this technical specification and other cited references, the most stringent shall prevail. If necessary, the SELLER may revert to BUYER for clarification.

3. DEFINITIONS AND ABBREVIATIONS

3.1. DEFINITIONS

All Terms and definitions are established in the latest revision I-ET-3010.00-1200-940-P4X-002 - GENERAL TECHNICAL TERMS, added to definitions from ISO 21457.

3.2. ABBREVIATIONS

Terms, definitions and abbreviated terms shall be as defined in ISO 21457, with the addition of the following abbreviated terms:

CA	Corrosion Allowance
CS	Carbon Steel
CRA	Corrosion Resistance Alloy
CLR	Crack Length Ratio
CSR	Crack Sensitivity Ratio
CTR	Crack Thickness Ratio
LTCS	Low Temperature Carbon Steel
DSS	Duplex Stainless Steel
SDSS	Super Duplex Stainless Steel
HC	Hydrocarbon
FRP	Fiber Reinforced Polymer
GRP	Glass – Reinforced Polymer
MDS	Material Data Sheet
NDE	Non-Destructive Examination
P&ID	Piping & Instrumentation Diagram

TSA Thermal Spray Aluminum
SCC Stress Corrosion Crack
RGD Rapid Gas Decompression

4. MATERIAL SELECTION PHILOSOPHY

The material selection shall be performed as oriented in ISO 21457, with the additional requirements and limitations herein stated.

4.1. MATERIAL SELECTION REPORT

4.1.1. Any material selection performed by SELLER shall be documented and submitted for BUYER evaluation in the form of a Material **Selection Report** as described in ISO 21457.

4.2. GENERAL PHILOSOPHY

4.2.1. The materials shall be selected considering the intended design life for the Unit of 30 years. This shall be applied to every line/equipment. Design of any line/equipment with a lower life with the intention of periodic subsequent substitution of any part is not acceptable.

4.2.2. When performing the material selection, regular carbon steel is the preferred material choice due mainly to its lower cost, mechanical properties and good weldability.

4.2.3. In order to evaluate the possibility of use of carbon steel the corrosion rate shall be determined for each line/equipment.

4.2.4. The design life shall be minimum as stated in contract, and the total corrosion allowance shall be defined as minimum of 1,6mm for both piping and equipment. The value of 3,2 mm shall be used as a general rule for equipment, and 6,4 mm shall be regarded as a maximum for both piping and equipment. Where this is satisfied the use of carbon steel is recommended. Where this is not satisfied or where other factors may influence, such as SCC, low temperature operation, galvanic corrosion or erosion, other materials which are more appropriate shall be selected.

4.2.5. For fluids with free water and CO_2 in the gas phase the corrosion rate shall be determined through simulations in accordance with the “de Waard and Milliams” model. Appendix A of this technical specification clarifies the use of this model. Corrosion rates for other systems shall be determined taking in account other aspects, such as oxygen content, temperature, chloride content, and so on. The worst case scenario shall always be considered (higher CO_2 content, higher H_2S content, higher oxygen content, lower pH, and so on). Where other corrosion models are used, they shall be indicated and detailed, and the input data and the calculated corrosion values shall be included in the report.

4.2.6. Additional corrosion control options that protect the carbon steel from premature failure may be studied and proposed. Such options could include internal coatings, cathodic protection or control of process fluids. The results of these studies could lead to a lower value of corrosion rate, thus turning the carbon steel appropriate for use. This may often lead to more than one corrosion control option being taken forward for further consideration (e.g., carbon steel with a corrosion allowance and inhibition system, versus carbon steel with a different corrosion allowance and a dehydration system). This kind of solution shall be evaluated by sensibility studies.

4.2.7. Unless otherwise agreed, the use of corrosion inhibitor as an option to protect carbon steel from premature failure is not acceptable.

4.2.8. **Sensibility studies** shall be performed to evaluate the effect of operational transient or temporary conditions (temporary by-pass or shut down of processing Units, for example), the effect of possible deviations from normal operating conditions (higher temperature, lower pH or higher water cut, for example) and the effect of failure of the corrosion control measures that protect the systems. These events would impair the initially predicted corrosion rate or may even cause SCC of the materials. The selection of more noble materials may result from these studies.

4.2.9. Operational conditions shall include upset conditions such as, but not limited to, dehydration or H_2S removal Units malfunction.

4.2.10. Line/equipment importance to the overall performance of the Unit shall also be considered when performing the material selection, as well as the historical failure data for that kind of system under similar operating conditions.

4.2.11. These studies shall be complemented by a **Low Temperature Effect Study**, which are events that may usually happen due to blowdown conditions or even due to an eventual leakage to atmosphere (through a flange, for example). Low temperatures (below 0ºC) may be achieved during these events, depending on the fluid properties and pressure, and may affect the material selection.

4.3. SELECTION PREMISES

In order to calculate the corrosion rate (per **Appendix A** or other corrosion model, as applicable), to perform the **Sensibility Studies** and the **Low Temperature Effect Study,** and to be able to perform an adequate material selection, the following premises shall be followed:

4.3.1. **Water Cut:** since the water content may vary greatly as the years pass, from the corrosion standpoint the highest water content shall be used for the calculation.

4.3.2. **pH:** for inlet fluid from reservoir the pH shall be considered as 4. Considering this data, SELLER shall calculate for each line/equipment the pH or may define based on previous experience on similar process conditions. If this cannot be performed, ISO 21457 recommendation for the pH shall be followed (pH 3,5 for solutions representing condensed water, as in gas-producing wells. pH 4,5 for solutions representing formation water, as in oil-producing wells).

4.3.3. **Dry Gas:** lines/equipment are considered dry if the minimum operating temperature is at least 10°C above the dew point temperature of the water, calculated on the basis of operating pressure. In these cases, the sensibility analysis shall be performed considering the efficiency of the dehydration unit used in the analysis reliability availability and maintainability (RAM) study.

4.3.4. **O_2 Content:** Injection water related lines/equipment are also usually free from oxygen. For these systems a sensibility study shall be performed considering the presence of oxygen on at least 2% of the lifetime, compensating for accidental ingress of the gas and for the Units shut down periods. Oxygen scavenger at producer water shall not be taken into consideration for material selection due to uncertainties of compatibility. Oil production lines/equipment are usually free from oxygen (oxygen content below 20 ppb). O_2 ingress in oil / gas systems due to the use of HC blanketing shall be evaluated in accordance with item 5.2.

4.3.5. **Stainless Steel SCC:** The following maximum operational temperature limits shall be applied to stainless steel lines/equipment:

- Austenitic Stainless Steel Type 316 or 316L: 50ºC maximum;
- Austenitic Stainless Steel Type 6Mo: 100ºC maximum;
- Duplex Stainless Steel Type 22Cr: 80ºC maximum;
- Super Duplex Stainless Steel Type 25Cr: 90ºC maximum;

4.3.5.1. The temperature limits indicated above are applicable for offshore atmospheric environment due to the risk of external SCC. These limits are also applicable for internal SCC caused by the deaerated fluid if chloride content is known to exceed 50 mg/l.

4.3.5.2. TSA and high performance coatings (without insulation) are considered as an efficient way of protecting stainless steel from a chloride stress corrosion cracking phenomena from offshore atmosphere.

4.3.6. **Liquid Carryover:** The liquid carryover at process systems shall be considered as established at equipment datasheets. The reliability of scrubber and K.O. drum shall be considered in order to evaluate the chloride content in gas streams (Cl <50mg/L).

4.3.7. **Galvanic Corrosion:** wherever dissimilar materials are to be directly connected, this shall preferably be performed by means of a flanged joint. In this case, electrical isolation kits may be required as defined at I-ET-3010.2D-1200-200-P4X-001 - PIPING SPECIFICATION FOR TOP SIDE and I-ET-3010.2E-1200-200-P4X-001 - PIPING SPECIFICATION FOR HULL.

4.3.8. **Low Temperature Effect:** is an event that may happen due to sudden pressure drop in pressure breaking accessories, such as restriction orifice, choke valves, pressure control valves, and so on.

4.3.8.1. This pressure drop will often lead to temperature reduction in the fluid and in the surrounding piping, so that it may affect the material selection. It is acceptable to change the selected material (change the basic piping spec) after some distance from the pressure breaking device, as long as the simulation properly indicates the low temperature affected length, but not less than 3m upstream the pressure break device. Low temperature effect shall also be considered for all static equipment and properly considered in its design.

4.3.8.2. Material selection for low temperature operation based on stress ratio allowances (e.g., Figure 323.2.2B from ASME B31.3, or Figure UCS-66.1 from ASME BPVC Section VIII Division 1) is not allowed.

4.3.8.3. For materials selection purposes, SELLER shall determine the lowest design temperature (LDT) or alternatively the minimum allowable temperature (MAT) for all unfired pressure vessels, heat exchangers, piping, piping components and valves (including control valves) or rotating equipment containing compressed gas or liquefied gas.

4.3.9. **Non-metallics Materials**: Those materials shall be compatible with the process fluid, including CO_2 fluid. Resistance to rapid gas decompression (RGD) of sealing materials is required in accordance with the I-ET-3010.00-1200-940-P4X-001 – POLYMERIC MATERIAL FOR CRITICAL GAS SYSTEMS.

4.3.10. **Coatings:** Coating shall be applied as predicted in I-ET-3010.00-1200-956-P4X-002- GENERAL PAINTING. Coating in conformance with IOGP S-715 are considered satisfactory.

5. SPECIFIC REQUIREMENTS

5.1. COMPLIANCE WITH ISO 15156 – SOUR SERVICE

5.1.1. It is SELLER scope of work to perform the evaluation of applicability of ISO 15156 requirements for all lines and equipment, considering the data provided in process simulation and datasheets. The following shall be done:

a) Definition of lines / equipment under sour service;

b) Development of new piping specs following ISO 15156 requirements.

5.1.2. Dehydration of gas, use of corrosion inhibitors or even H_2S scavengers will not, in any case, be accepted as measures to waive or reduce the requirement of using H_2S resistant materials.

5.1.3. For H_2S partial pressure calculation it shall always be considered that the H_2S Removal Unit, (in this project know as CO_2 Removal Unit), may be by passed or even shut down. The lowest anticipated pH and the highest H_2S partial pressure shall always be considered. H_2S partial pressure shall always be calculated from the design pressure.

5.1.4. For carbon and low alloy steel, H_2S partial pressure shall be calculated for every line/equipment in order to define whether ISO 15156-2 requirements shall be followed.

5.1.5. For carbon and low alloy steel where the H_2S partial pressure exceeds 0.3 kPa the whole material selection shall be made based on ISO 15156-2, Annex A item A.2 (selection as per Option 1 from ISO 15156).

5.1.6. There are no inferior limits to H_2S partial pressure in order to consider the requirements of ISO15156-3 for corrosion resistance alloys (i.e., whenever there is H_2S, the CRA will be under sour service).

5.1.7. The use of ISO 15156-1 item 8, qualification of unlisted materials, may be used only with prior BUYER approval.

5.1.8. Painting or any other type of internal coating (TSA included) shall not be considered as an efficient way of protecting the material from a stress corrosion cracking (SCC) phenomena due to H_2S service.

5.1.9. In case of sour service, all manufacturing and welding procedures shall be qualified considering requirements of piping/equipment construction codes plus the applicable requirements of ISO 15156.

5.1.10. Sour service shall also be considered in systems associated with tanks where biogenic H_2S may be produced (slope tanks; produced water tanks).

5.1.11. Piping specs that are meant to be compliant with ISO 15156 shall have a suffix N added to its name (e.g., spec B3N would be equivalent to spec B3, but with ISO 15156 requirements added to the materials). Sour and non-sour materials shall be properly identified, and due traceability shall be assured in order to avoid misuse.

5.1.12. Piping components shall be procured as per IOGP S-563 MDS's, with the following additions:

5.1.12.1. Where H2S partial pressure exceeds 0,05 psia (0.0003 MPa) and the aqueous phase total sulfide (ppmw) is below 2000, suffix 'S' shall be added to the MDS's (sour services additional supplementary requirements are applicable).

5.1.12.2. Where H2S partial pressure exceeds 0,05 psia (0.0003 MPa) and the aqueous phase total sulfide (ppmw) exceeds 2000, suffix 'SH' shall be added to the MDS's (sour services additional supplementary requirements are applicable plus HIC testing and UT examination).

5.1.13. For static equipment (e.g.: pressure vessels, heat exchangers, filters, drums, and so on), as a rule, HIC testing is only applicable for rolled plates in the condition established in Table 1 below or if determined at project specific document. HIC testing is not applicable for seamless pipes, castings, and forgings components. HIC testing is not applicable for wrought accessories, unless they are fabricated from products that originate from rolled plates. HIC testing need not be applied for parts that will be fully protected by a weld overlay or clad.

Table 1: HIC requirements for static equipment components

pH	Partial pressure of H_2S in the gas phase (MPa/psia)		
	< 0.0003 MPa / 0.05 psia	> 0.0003 MPa / 0.05 psia	
	Aqueous phase total sulfide (ppmw)		
	<50	50-2000	>2000
<4	N/A	Clean steel required	Clean steel and HIC test required
4 to 7,6	N/A	N/A	Clean steel required
>7,6	N/A	Clean steel required if HCN-present	Clean steel and HIC testing required

5.1.14. Where Table 1 indicates the need for HIC testing, one plate per lot shall be HIC tested in accordance with NACE TM0284, using test solution A.

5.1.15. Where Table 1 indicates the use of a clean steel, the following requirements applies for the steel plates:

- Be vacuum degassed.
- Be fully killed, made to fine grain practice.
- Either normalized, TMCP or Q&T.
- Maximum sulfur (S) content of 0.001 wt%.
- Maximum phosphorus (P) content of 0.010 wt%.
- Inclusion shape control shall be applied.

5.1.16. The acceptance criteria for HIC testing for sour service shall be in accordance with the following:

- CLR lesser than or equal to 15 % per specimen.
- CTR lesser than or equal to 5 % per specimen.
- CSR lesser than or equal to 2 % per specimen.
- 5 mm (0,2 in) maximum individual crack length.
- Ultrasonically tested as per ASTM A578 S1, S2.1 or EN 10160 quality classes S2 (plate) E3 (edge).

5.2. O_2 INGRESS IN OIL / GAS SYSTEMS DUE TO THE USE OF HC BLANKETING

5.2.1. The O_2 ingress in gas systems may happen during start-up of structural gas tank recovery system due to the use of hydrocarbon blanketing.

5.2.2. SELLER shall consider for material selection purpose the values listed at respective datasheets.

5.2.3. All material selected at basic design considered the eventual presence of O_2 in gas stream in accordance with process simulation (with the values defined at data sheet).

5.2.4. SELLER shall evaluate if there is a possibility of reaction between H_2S and O_2 with consequent formation of S_8, in case of operational condition of equipment / package within the envelope. If the case, the detailed data sheet shall include this information.

5.2.4.1. In this case, BUYER shall be consulted in order to determine if the presence of S_8 shall be considered in downstream equipment.

6. MATERIAL APPLICATION – LIMITS AND RECOMMENDATIONS

6.1.1. The following restrictions are applicable to the most commonly used materials for topside lines/equipment.

6.1.2. All metallic materials shall be associated with an ASTM or ASME BPVC Sec II. Other materials standards require BUYER approval.

6.1.3. Non-metallic materials shall also observe a recognized standard and be type approved, as applicable.

6.1.4. The use of stainless steel type 304 (UNS S30400) or 304L (UNS S30403) alloys is not acceptable for pressurized or high stressed parts, not even for internals, gaskets or fasteners.

6.1.5. The use of aluminum material shall be limited (BUYER approval required). For heat exchangers and pressure vessels, and other pressure retaining parts this material is not acceptable.

6.1.6. The materials listed in Table 2 may be used for the services therein listed.

Table 2 - Typical Material Selection for Common Services

Material	Usual Service	Notes
Carbon Steel	Dry gas; Dry Inert gas; Closed circuit water systems (cooling and heating systems); Closed Drain; Noncorrosive hydrocarbons	a) Regular carbon steel is usually limited to applications where the design code does not require toughness testing for the material and the welding procedures. For temperatures for which the design code would require toughness testing of the materials, LTCS shall be selected instead.
Low Temperature Carbon Steel		a) May be needed due to low temperature that may come from process requirements, or due to blowdown events. b) Low temperature carbon steel shall always be fully killed, made to fine grain practice
SS316/316L	Noncorrosive hydrocarbons Corrosive hydrocarbons Flare Fresh/ Potable Water Distilled water Diesel Instrumentation Hydraulic fluid Chemical injection Fluids sensitive to corrosion products	a) First choice of material when the calculated corrosion rate does not allow the use of carbon steel; b) Shall be selected as 316/316L dual certificate type. The dual certificate means that the material shall have the mechanical properties of the grade 316 and attend the chemical composition of the grade 316L. c) Shall not be used in lines with aerated sea water; d) Shall not be used for Sodium Hypochlorite or DBNPA biocide; e) Shall not be used as pressure retaining part in lines with operating temperature that exceeds 50ºC, unless properly protected by a suitable coating system; f)May be used as cladding/overlay for vessels, usually when there is no post weld heat treatment during fabrication;
Duplex (DSS) and Super duplex (SDSS)	Noncorrosive hydrocarbons Corrosive hydrocarbons Flare Diesel Instrumentation Chemical injection Deaerated Injection Water Produced Water	a)Usually applied in systems where the corrosivity does not allow the use of carbon steel, but in which the operating temperature exceeds the limit for the use of 316L SS; b)Shall not be used as pressure retaining part in systems with aerated sea water. For injection water duplex material is limited to 50°C. c)Shall not be used as pressure retaining part in lines with operating temperature that exceeds 80ºC (DSS) or 90ºC (SDSS), unless properly protected by a suitable coating system; d)In high pressure systems SDSS is preferred instead of DSS due to its higher mechanical properties, which implicates in smaller thicknesses and less weight for lines and equipment; e)May be used as cladding/overlay for vessels, as long as there is no post weld heat treatment during fabrication.
Carbon Steel Cladded with Inconel	Corrosive hydrocarbons Deaerated Injection Water Produced Water	a)Usually applied where process conditions would limit the application of DSS or SDSS. This may be due to operating temperature limitations or due to H_2S service requirements; b)Maximum allowed iron dilution on the overlay is 10% measured at the surface; c)The cladding shall be metallurgical bond produced by hot rolling, co-extrusion or weld overlay. Minimum cladding thickness shall be 3 mm;
3,5Ni	Noncorrosive hydrocarbons Corrosive hydrocarbons	a)Cladding is mandatory for 3,5Ni alloy in case of sour service or liquid/supercritical CO_2. b)Usually applied in high pressure systems where the depressurization may lead to low temperatures on the surrounding materials; c)In dehydrated fluids with high CO_2 content, due to its supercritical behavior CO_2 may cause very low temperatures during blowdown events or in the event of a leakage (ranging from -60ºC to -100ºC). d)Where H_2S service is applicable these materials will require qualification by testing in accordance with I-ET-3010.00-1200-900-P4X-001 - ADDITIONAL REQUIREMENTS FOR SOUR SERVICE 3.5% NICKEL STEEL (even when cladding is applied)

(Table 2 continued)

Material	Usual Service	Notes
Inconel	Noncorrosive hydrocarbons Corrosive hydrocarbons Flare	a)Usually applied in high pressure systems where the depressurization may lead to low temperatures on the surrounding materials, especially for fluids with high CO_2 content. In fluids with high CO_2 content, due to its supercritical behavior CO_2 may cause very low temperatures during blowdown events or in the event of a leakage (ranging from -60ºC to -100ºC); b)For small diameters and small accessories, where cladding is not feasible or economical, whole 625 components may be used in lieu of CS+625.
6Mo	Chemical injection systems Instrumentation Noncorrosive hydrocarbons Corrosive hydrocarbons	a) Shall be used for tubbing in Chemical injection systems and general application for instrumentation tubbing. b) 6Mo is an acceptable material for pressure retaining parts with requirements for low temperature and for high temperature corrosion resistance to CSSC.
Cu-Ni	Fire water Foam lines Sea water	a)Shall be used for the firefighting lines that operate with sea water, as well as the foam lines; b)May be used for other systems that operate with seawater, including seawater collecting system; c)In any case the internal flow velocity shall be limited to a maximum of 3.5 m/s;
GRP	Sodium Hypochlorite; Sea water; Produced water; Ballast. Closed Water systems Chemical injection Open Drain	a)Shall be used for the seawater systems b)Preferred material for open drain systems, whenever is acceptable by classification society and safety rules. c)Shall not be used for compressible fluids; d)GRP pressure vessels, tanks and filter shall be used wherever possible in water systems; the detailed GRP selection for equipment shall follow the requirements of I-ET-3010.00-1200-500-P4X-001 - NON METALLIC TANKS AND PRESSURE VESSELS DESIGN. e)GRP tertiary structures shall be used unless is not allowed (specific the location nonmetallic material due to fire hazards);
Internally coated carbon steel	Sodium Hypochlorite; Chemical injection Sea water and Fire Water; Produced water; Ballast. Closed Water systems Open Drain Air system Oily Water (Bilge; Cargo; Slope)	a)Shall be selected only if not possible to use GRP. b)Shall only be used with addition of corrosion allowance; c)Shall not be used for high pressure systems (pressure above class 900, inclusive) or with high fluid velocities; d)Shall not be used in systems with strict solid content control; e)Shall comply with I-ET-3010.00-1200-956-P4X-002 – GENERAL PAINTING and I-ET-3010.00-1200-751-P4X-001 - ANODES SPECIFICATION FOR MECHANICAL EQUIPMENT
Galvanized carbon steel	Carbon Dioxide (without hydrocarbon); Venting; open drain	a)Shall not be used for flammable or combustible fluids; b)Shall not be used for high pressure systems (pressure above 600, inclusive); c)Shall not be used for fluids with operating temperatures above 50°C; d)The galvanized carbon steel shall be coated externally (i.e., organic coating) on top of the galvanized layer.
PVC/ CPVC	Chilled water; potable water; Chemical injection; closed water systems.	a) Shall not be used in areas subject to UV and heavy cargo handling (Classification Society rule shall be consulted). b) For handling potable water system, the legislation regarding potability shall be complied. c) BUYER shall be consulted in case of equipment manufactured with this type of material with regard to validate standard for mechanical calculation.
Titanium	Sodium Hypochlorite; Chemical injection Sea water and Fire Water; Produced water; Corrosive liquid hydrocarbons	a) Titanium tubing and fittings: used for DBNPA biocide. Hastelloy C276 is an alternative; b) Shall be used for plate heat exchangers in contact with process fluid or aerated seawater
Nickel Aluminum Bronze	Fire water and sea water	a) Material for pressure retaining parts and for internals in aerated seawater.

7. REQUIREMENTS FOR EQUIPMENT / COMPONENTS

7.1. ADDITIONAL REQUIREMENTS FOR MATERIAL SELECTION FOR PIPING

7.1.1. Material selection for piping valves shall be performed in accordance with the rules herein listed and shall also be in conformance with Annex A of I-ET-3010.2D-1200-200-P4X-001 - PIPING SPECIFICATION FOR TOPSIDE and I-ET-3010.2E-1200-200-P4X-001 - PIPING SPECIFICATION FOR HULL.

7.1.2. Materials for all and every component in piping systems, including its accessories and special design parts such as valves, expansion joints, strainers and others, shall be selected following the same rules and recommendations as applicable to the pipe base materials. This includes all internal parts from these components that are exposed to the conducted fluids, as well as for any welds therein.

7.1.3. For process related lines where CRA material is indicated, the operational temperature limits of material established at item 4.3.5.1 shall be observed. The application of external coating is an alternative for enabling the use of these materials above the cited temperature limits.

7.1.4. Classification Societies may have limits to the use of non-metallic materials in certain systems. In these cases, an alternative material shall be selected that will offer the same corrosion resistance (i.e., Cu-Ni 90/10).

7.1.5. SELLER shall consider flowrate regime (stagnant, intermittent or continuously flowing) when evaluating corrosivity and selecting piping material.

7.1.6. Gaskets materials shall be compatible with fluid and operational temperatures to avoid risk of leakage. Hydraulic Gasket paper shall not be used for hot water piping systems. Graphite filled gaskets shall not be used for conductive fluids (p.e., waters).

7.1.7. The selection of schedules higher than the minimum calculated are recommended where piping vibration is known to happen. This is usually true for piping connecting to rotating equipment and with multiphase flow. Compliance with the requirements of the Energy Institute Guide for Vibration is a must, as indicated in the technical specification for piping design.

7.2. ADDITIONAL REQUIREMENTS FOR MATERIAL SELECTION FOR PROCESS EQUIPMENT

7.2.1. Material selection for process equipment shall be performed in the same way as detailed for the piping (item 7.1 above), with the additional considerations herein listed.

7.2.2. If compact type heat exchangers are selected (PCHE or similar) and they are manufactured in CRA, all piping upstream of the equipment shall be selected in CRA or shall be protected from corrosion with an internal corrosion protection (coating) so that it shall not contaminate the heat exchanger core.

7.2.3. Plate heat exchangers shall be selected in titanium, since it has superior mechanical properties (thinner plates) and is not prone to SCC. This requirement is not mandatory for plate heat exchangers of ancillary systems.

7.2.4. For shell and tube heat exchangers, the baffles shall always be selected in SS or other CRA material for all cases where the tubes are of CRA material, and the fluid is conductive.

7.2.5. The use of CS + Organic Coating for process equipment dealing with fluids with elevated corrosivity is essentially forbidden, especially when the equipment is connected to lines selected in CRA.

7.2.6. Where the process equipment is connected to lines selected in Carbon steel with Organic

Coating, the use of the same kind of solution for the protection of the equipment itself is essentially allowed, subject to BUYER approval. Additional corrosion protection measures shall be taken in these cases, and shall include, but are not limited to, additional cathodic protection and CRA overlay of critical and sealing areas (for example flange sealing areas).

7.2.7. For cathodic protection of equipment see requirement of I-ET-3010.00-1200-751-P4X-001 - ANODES SPECIFICATION FOR MECHANICAL EQUIPMENT.

7.2.8. Equipment internals shall always be selected in CRA. Different materials require BUYER approval.

7.2.9. Material selection within any equipment shall be performed in a way to prevent galvanic coupling and corrosion.

7.2.10. Where clad is mentioned as an option for pressure retaining parts, it shall always guarantee metallurgical bonding between the CS substrate and the CRA (coextrusion, colamination, or welding overlay). DSS and SDSS CRA clads shall not be used if the equipment requires any kind of heat treatment. Weld overlay shall be performed as described in I-ET-3010.00-1200-955-P4X-001- WELDING.

7.2.11. For electric process heaters, the sheath element shall be as stated at I-ET-3010.00-1200-498-P4X-002 - ELECTRIC PROCESS HEATERS.

7.2.11.1. The selection of tubesheets material and weld consumable for dissimilar welds shall be such that fragile microstructures is avoided.

7.2.12. For electric utility heaters, the sheath elements shall be selected considering the fluids characteristics being handled, the possibility of chloride stress corrosion cracking and the possibility of microbiological corrosion. The minimum material shall be SS316.

7.3. ADDITIONAL REQUIREMENTS FOR ROTATIVE EQUIPMENT

7.3.1. Material selection for pumps shall follow the criteria stablished in ISO 21457, API 610 and ASME B73.1.

APPENDIX A – CO_2 CORROSION RATE PREDICTION BASED ON "DE WAARD AND MILLIAMS"S MODEL

This model gives an estimative of the corrosion rate for carbon steel materials carrying CO2 in water containing flows, considering different conditions for temperature, pressure and CO2 molar fraction.

A.1 BASIC CORROSION RATE

The "de Waard and Millians" base philosophy determines that for a dry flow (no water in the mixture) the corrosion rate will be negligible. For water containing flows the basic corrosion rate may be calculated as follows:

$$\log(CR) = 5.8 - \frac{1710}{T} + 0.67\log(P_{PCO2}) \qquad \text{(Eq. 1)}$$

Where:

CR – Corrosion Rate (mm/year)

PPCO2 – CO2 partial pressure (bar)

T – Temperature in K

The CO2 partial pressure is calculated as follows (PPCO2):

$$P_{PCO2} = \frac{\%CO_2}{100} \times P \qquad \text{(Eq. 2)}$$

Where:

%CO2 – CO2 Molar Fraction

P – Total Pressure (bar)

For pressures above 100 bar (P > 100 bar) the gas fugacity is used in lieu of the partial pressure. In this case Equation 1 becomes:

$$\log(CR) = 5.8 - \frac{1710}{T} + 0.67\log(f_{CO2}) \qquad \text{(Eq. 3)}$$

$$f_{CO2} = a \times P_{PCO2} \qquad \text{(Eq. 4)}$$

Where:

fCO2 – CO2 fugacity (bar)

a – Fugacity Coefficient

In cases where the fugacity coefficient is not known, the corrosion rate obtained from Equation 1 may be corrected by multiplying it by the following factor:

$$\log F_{system} = 0.67(0.0031 - \frac{1,4}{T}) \times P$$ (Eq. 5)

Where:

Fsystem – Correction Factor for the gas fugacity (multiplies CR obtained from Eq.1)

The new corrosion rate in this case is:

$$CR_{fugacity} = CR_{EQ1} \times F_{SYSTEM}$$ (Eq.6)

From this value it is possible to calculate an equivalent CO2 fugacity by inverting Equation 3 as follows:

$$f_{CO2_{Equivalent}} = 10^{\left(\frac{\log(CR_{fugacity}) - 5.8 + \frac{1710}{T}}{0.67}\right)}$$

(Eq.7)

A.2 CORRECTION FACTORS FOR THE CORROSION RATE

The corrosion rate obtained in A.1 above is generally conservative, and it does not consider environment effects that may help reduce this rate. The following correction factors come from the work of "Lotz and de Ward".

I - Scale Factor:

Is determined by the following equation:

$$\log F_{SCALE} = \frac{2400}{T} - 0.6 \log f_{CO2} - 6.7$$ (Eq.8)

$$If\ F_{SCALE} > 1, F_{SCALE} = 1$$

This factor multiplies the corrosion rate obtained in A.1. The Scale Temperature is the one where log (Fscale) equals zero, so that:

$$T_{SCALE}(K) = \frac{2400}{6.7 + 0.6\log(f_{CO2})}$$ (Eq.9)

The Scale Temperature reduces with increasing CO2 partial pressure. Equations 8 and 9 may be combined as follows:

$$\log(F_{SCALE}) = 2400 \times \left(\frac{1}{T} - \frac{1}{T_{SCALE}}\right)$$ (Eq.10)

This factor may only be used if the operating temperature is above 60ºC and also above the Scale Temperature.

II- Oil Factor:

For flows containing hydrocarbons and water:

If the fluid contains less than 20% water and more than 50% C5+, the oil tends to cover the surface and the corrosion rate diminishes. In this case an Oil Factor of 0.3 may be used.

For all remaining conditions of multiphase flow an Oil Factor of 1.0 is recommended.

III- pH Factor:

The initial theoretical pH of the solution may be calculated for a water system saturated with CO2:

$$pH_{Calculado} = 3.71 + 0.00417 \times t - 0.5 \log(P_{PCO2}) \quad \text{(Eq.11)}$$

Where:

t - Temperature in degrees Celsius

Corrosion rates obtained from Equation 1 or Equation 3 are based on saturated solutions. For this condition the final pH may be calculated by the following relations:

$$pH_{sat\ 1} = 1.36 + \frac{1307}{t + 273} - 0.17 \log(fCO_2) \quad \text{(Eq.12)}$$

$$pH_{sat\ 2} = 5.4 - 0.66 \log(fCO_2) \quad \text{(Eq.13)}$$

$$pH_{sat} = smaller(pH_{sat\,1}, pH_{sat\,2})$$

The difference between the actual pH and the saturation pH influences the corrosion rate. Actual pH that is lower than the saturation pH tends to increase the initially calculated corrosion rate. Actual pH that is higher than the saturation pH diminishes the calculated corrosion rate.

Where this actual pH is not known the recommendations from ISO 21457 shall be followed.

The pH Factor may be calculated as follows.

If pH saturation > pH actual (corrosion rate increases):

$$\log F_{pH} = 0.32 \times (pH_{sat} - pH_{actual}) \quad \text{(Eq.14)}$$

If pH saturation < pH actual (corrosion rate diminishes):

$$\log F_{pH} = -0.13 \times (pH_{actual} - pH_{sat})^{1.6} \quad \text{(Eq.15)}$$

If pH saturation = pH actual, no correction factor is needed.

The model does not permit the combination of the Scale Factor with the pH Factor, so that if Fscale < 1, then FpH must be considered as 1.