*Microsoft Word® 2016 / I-ET-3000.00-1500-310-PEK-003 – SUBSEA SEAWATER PUMP 10.000 PSI.docx*

## REVISION INDEX

| REV. | DESCRIPTION AND/OR REVISED SHEETS |
|---|---|
| | Based on 3000.00-1500-310-PEK-001 |
| 0 | ORIGINAL |
| A | Changes in 4.2, 4.3, 4.13, 4.18, 5.1.13, 5.5, where highlighted in GREY |

| | REV. 0 | REV. A | REV. B | REV. C | REV. D | REV. E | REV. F | REV. G | REV. H |
|---|---|---|---|---|---|---|---|---|---|
| DATE | 19/10/2023 | 25/03/2024 | | | | | | | |
| DESIGN | EES | EES | | | | | | | |
| EXEC. | B2N8 | B2N8 | | | | | | | |
| CHECK | MA9N | ES24 | | | | | | | |
| APRROV, | UP65 | U4SZ | | | | | | | |

# INDEX

# 1 INTRODUCTION

The objective of this technical specification is to establish the requirements for SUBSEA SEAWATER 10.000 PSI Pumps.

## 1.1 Reference Documents

### 1.1.1 Codes, Standards, Rules and Regulations

The latest issue of the reference standards shall be used unless it is specified in the table below or otherwise agreed. Other recognized standards may be used, provided that the SUPPLIER proves that they meet or exceed the requirements of the standards referenced below.

| | |
|---|---|
| [1] Resolução ANP nº 41 – DOU 13.10.2015 | Sistema de Gerenciamento de Segurança Operacional de Sistemas Submarinos – SGSS (Management System of Operational Safety of Subsea Systems) |
| [2] ISO 13628-15:2011 | Petroleum and natural gas industries – Design and operation of subsea production systems – Part 15: Subsea structures and manifolds |
| [3] API 6A 2018 | Specification for Wellhead and Tree Equipment |
| [4] ISO 13628-1:2005 | Petroleum and natural gas industries Design and operation of subsea production systems – Part 1: General requirements and recommendations |
| [5] ISO 13628-8 | Design and operation of subsea production systems Part 8: Remotely Operated Vehicle (ROV) interfaces on subsea production systems |
| [6] ISO 10423:2009 | Petroleum and natural gas industries Drilling and Production Equipment Wellhead and Christmas Tree Equipment |
| [7] API RP 17N, 2nd Ed., Addendum 1 – May 2018 | Recommended Practice on Subsea Production System Reliability, Technical Risk, and Integrity Management |
| [8] API RP 17Q | Recommended Practice on Subsea Equipment Qualification |
| [9] API RP 17V | Recommended Practice for Analysis, Design, Installation, and Testing of Safety Systems for Subsea Applications FIRST EDITION; ERTA 1: July 2015 |
| [10] API STANDARD 17O | Standard for Subsea High Integrity Pressure Protection Systems (HIPPS) |
| [11] API STD 610 — 11th edition | Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries |
| [12] API TR 684-1 | API Standard Paragraphs Rotordynamic Tutorial: Lateral Critical Speeds, Unbalance Response, Stability, Train Torsionals, and Rotor Balancing |
| [13] API STD 682 | Pumps — Shaft Sealing Systems for Centrifugal and Rotary Pumps |
| [14] API 17X | Recommended Practice for Subsea Pump Module Systems |
| [15] API STD 671 | Special-purpose Couplings for Petroleum, Chemical, and Gas Industry Services |

| | |
|---|---|
| [16] ASME BPVC section VIII | Rules for Construction of Pressure Vessels |
| [17] ISO 15156-3 | Petroleum and natural gas industries — Materials for use in H2S-containing environments in oil and gas production — Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys |
| [18] API Std 670 | Machinery Protection Systems |
| [19] DNVGL-RP-F303 | Subsea Pumping Systems |
| [20] API STD 526 - SEVENTH EDITION; ERTA: September 2018 | Flanged Steel Pressure-relief Valves |
| [21] API STD 520 PART I - TENTH EDITION | Sizing, Selection, and Installation of Pressure-relieving Devices Part I—Sizing and Selection |
| [22] API STD 2000 - Seventh Edition | Venting Atmospheric and Low-pressure Storage Tanks |
| [23] ISO 21940-11 | Mechanical vibration - Rotor balancing - Part 11: Procedures and tolerances for rotors with rigid behavior |
| [24] ISO 17781 | Petroleum, petrochemical and natural gas industries — Test methods for quality control of microstructure of ferritic/austenitic (duplex) stainless steels |
| [25] NACE MR0175 | Petroleum, petrochemical, and natural gas industries — Materials for use in H2S-containing environments in oil and gas production — |
| [26] DNVGL-RP-F112 | Duplex stainless steel - design against hydrogen induced stress cracking |
| [27] ISO 23936-2 | Petroleum, petrochemical and natural gas industries — Non-metallic materials in contact with media related to oil and gas production — Part 2: Elastomers |
| [28] ISO 23936-1 | Petroleum, petrochemical and natural gas industries — Non-metallic materials in contact with media related to oil and gas production — Part 1: Thermoplastics |
| [29] Norsok M-710 | Qualification of non-metallic materials and manufacturers – Polymers |
| [30] DNV RP B401 | Cathodic protection design |
| [31] ISO 21457 | Petroleum, petrochemical and natural gas industries — Materials selection and corrosion control for oil and gas production systems |
| [32] DNV RPF112 | Duplex stainless steel - design against hydrogen induced stress cracking |
| [33] IEC 61511 | Functional safety of electrical/electronic/ programmable electronic safety-related systems |

### 1.1.2 PETROBRAS Documents

| | |
|---|---|
| [34] RM | Material Requisition(s) with technical aspects and scope specific to the project |

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|---|---|
| [35] I-ET-3000.00-1500-310-PEK-004 | Subsea Raw Water Injection System 10.000 Psi |
| [36] Fluids TS | Technical Specification(s) with the characteristics of the fluids of the project |
| [37] Engineering Diagram | Base Case Engineering Diagram of the Equipment/System |
| [38] Control System TS | Control System Specification(s) of the project |
| [39] Subsea Electrical Power System TS | Subsea Electrical Power System Specification(s) of the project |
| [40] Subsea Pump Datasheet | |
| [41] ET-3000.00-1500-600-PEK-005 | Requisitos de Estruturas de Equipamentos Submarinos |
| [42] ET-3000.00-1500-600-PEK-006 | Requisitos Gerais de Equipamentos Submarinos |
| [43] ET-3000.00-1521-600-PEK-001 | Projeto de Interfaces para Operações com ROV / E&P |
| [44] ET-3000.00-1500-610-PEK-002 | Eslingas e Skids para Transporte de Equipamentos Submarinos |
| [45] ET-3000.00-1500-251-PEK-001 | Fixadores em Aço Baixa Liga de Alta Resistencia para aplicação Submarina / Instalações Submarinas |
| [46] ET-3000.00-1500-251-PEK-002 | Rastreabilidade de Fixadores de Alta Resistencia para Utilização o Submarina / Instalações Submarinas |
| [47] N-2037 | Pintura de Equipamentos Submersos em Água do Mar |
| [48] N-1852 | Estruturas Oceânicas Fabricação e Montagem de Unidades Fixas |
| [49] N-133 | Soldagem |
| [50] DE-3500.00-1516-273-PPC-738 | Receptáculo para Dual Hot Stab |
| [51] DE-3000.00-1500-270-PEK-001 | HUB de Instalação Padrão Petrobras |
| [52] ET-3000.00-1500-600-PEK-004 | Documentação Técnica para Equipamentos Submarinos |
| [53] ET-3000.00-1500-940-PEK-001 | Projeto de Proteção Catódica para Equipamentos Submarinos |
| [54] ET-3000.00-1514-270-PAZ-001 | Sistema de Conexão Vertical Direta com Pescoço de Ganso |
| [55] ET-3000.00-1500-220-PEK-002 | Requisitos Gerais de Projeto e Testes de Válvulas e Atuadores Submarinos |
| [56] ET-3000.00-1500-221-PEK-001 | Requisitos Específicos de Projeto e Testes de Válvulas Gaveta para Aplicação Submarina. |
| [57] Special Operations Fluids TS | Fluids for Special Operations applicable in specific projects |
| [58] Subsea Motor-Pump Transducer System TS | Subsea Motor-Pump Transducer System |
| [59] Topside Interface TS | Topside Equipment Module Interface with FPSO/FPU |
| [60] ET-3000.00-1500-600-PEK-008 | Instalação de Equipamentos Submarinos |

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|---|---|---|
| [61] | Choke Valves Datasheet | |
| [62] | ET-3000.00-1500-229-PEK-001 | REQUISITOS DE PROJETO E TESTES DE VÁLVULAS CHOKE PARA APLICAÇÃO SUBMARINA |

### 1.1.3 Order of Precedence

If there is any conflict between requirements, the following order of precedence shall be applied ((i) being higher in the order):

i. Resolução ANP nº 41 – DOU 13.10.2015
ii. RM;
iii. I-ET-3000.00-1500-310-PEK-004 [35];
iv. This Technical Specification.
v. API 6A [3]
vi. API RP 17V [9]
vii. Other PETROBRAS documents.
viii. Other ISO Standards and RPs.
ix. API Standards and RPs.
x. Other Standards and RPs.

Ref. [14] shall only be used where explicitly named in this specification.

## 1.2 TERMS, DEFINITIONS, ACRONYMS AND ABREVIATIONS

### 1.2.1 Acronyms and Abbreviations

BF: Barrier Fluid

BFHPU: Barrier Fluid Hydraulic Power Unit

BSRWI: Subsea Seawater Pump

CAT: Component Acceptance Test

CKM: Choke RETRIVABLE MODULE

CMAT: Complete Model Acceptance Test

CRA: Corrosion Resistant Alloy

DE: Drive End

DPIEF: Define, Plan, Implement, Evaluate, Feedback

DRS: Diverless Rigid Spool

EBS: Pumping Station

EBSRWI: Subsea Raw Water Injection Pumping Station

ESRWI: Subsea Raw Water Injection Station

EFAT: Extended Factory Acceptance Tests

EFL: Electric Flying Lead

ESD: Emergency Shutdown

ET = TS

FAT: Factory Acceptance Testing

FMECA: Failure Modes, Effects, and Criticality Analysis

FWKO: Free Water Knockout

FPSO: Floating Production, Storage and Offloading Vessel

GVF: Gas Volume Fraction

HAZID: Hazard Identification

HAZOP: Hazard and Operability Study

HFL: Hydraulic Flying Lead

HPU: Hydraulic Power Unit

ID: Internal Diameter

IM-FMECA: Integrity Management Failure Modes, Effects, and Criticality Analysis

ITMM: Inspection, Testing, Monitoring, and Maintenance

LAS: Low Alloy Steel

MATIC: Manufacture, Assembly, Testing, Installation, and Commissioning

MAY: used when alternatives are equally acceptable

MBSRWI: Subsea Raw Water Injection Retrievable Module

MCV: Vertical Connection Module

MCSF: Minimum Continuous Stable Flow

MFB: Barrier Fluid Subsea Module

MRT: Mechanical Run Test (= Mechanical Running Test), according to [11]

NDE: Non-Drive End

NP: Part Number

NPS: Nominal Pipe Size

NPSH: Net Positive Suction Head according to ref. [11]

P&ID: Piping and Instrumentation Diagram

P-FMECA: Process Failure Modes, Effects, and Criticality Analysis

PLEM: Pipeline End Manifold

PLET: Pipeline End Termination

PSL: Product Specification Level, according to ISO 13628-4: 2010 [2] and ISO 10423: 2009 [5]

PSV: Pressure Safety Valve

PVT: Performance Verification Testing

P-Test: Performance Test according to ref. [11], [12] and [13].

QA: Quality Assurance

QC: Quality Control

Q-FMECA: Qualification Failure Modes, Effects, and Criticality Analysis — ref. [8]

RAM: Reliability, Availability, and Maintainability

RBI: Risk Based Inspection

RIAD: Reliability and Integrity Assurance Document

RIM: Reliability and Integrity Management

RM: Material Requisition

ROV: Remotely Operated Vehicle

RP: Recommended Practice

SEPS: Subsea Electrical Power System

SHALL: used when a provision is mandatory

SHOULD: used when a provision is not mandatory, but is recommended as a good practice

SIS: Safety Instrumented Systems. According to reference [10]

SIT: System Integration Test

SMAT: Subsystem Model Acceptance Test

SMPTS: SUBSEA MOTOR-PUMP TRANSDUCER SYSTEM. As defined in [58].

SMYS: Specified Minimum Yield Strength

SRWI SYSTEM: Subsea Raw Water Injection System

SRWIFB: Subsea Raw Water Injection Flow Base

SVSD = SVFD: Subsea Variable Frequency Drive= Subsea Variable Speed Drive

TRAR: Technical Risk Assurance Review

TRC: Technical Risk Categorization

TS: Technical Specification = ET

UTA: Umbilical Termination Assembly

VFD= VSD: Variable Frequency Drive= Variable Speed Drive

XT: Christmas Tree

### 1.2.2 Definitions

1.2.2.1 SUPPLIER: Contractor (Subsea Raw Water Injection System SUPPLIER)

1.2.2.2 Critical Element of Operational Safety: any Critical Equipment, System or Procedure of Operational Safety, according to [1].

1.2.2.3 Critical Equipment of Operational Safety: any equipment or structural element of the system whose failure could cause or contribute to operational accidents, according to [1].

1.2.2.4 Critical Procedure of Operational Safety: any procedure or criteria used to control operational risks, according to [1].

1.2.2.5 Critical System of Operational Safety: any engineering control system designed to maintain the system inside its Safety Envelope, to stop partially or totally the system in case of operational safety failure, and to reduce risks to personnel and environment exposed to failure consequences, according to [1].

1.2.2.6 Package: A named system, subsystem, or defined set of components considered as a single entity for the purposes of a design study or for procurement (e.g., subsea tree, control system).

1.2.2.7 Safety Envelope: Operational limits and conditions defined during system Detailed Design stage and complying with applicable industry standards that shall not be surpass and that guarantee the integrity and operational safety of the system, according to [1].

# 2 SUBSEA RAW WATER INJECTION SYSTEM APPLICATION CONDITIONS AND PARAMETERS

2.1 Each SUBSEA RAW WATER INJECTION SYSTEM BSRWI shall be designed to withstand all conditions and parameters described in RM [34] and Fluids TS [36].

2.2 Each SUBSEA RAW WATER INJECTION SYSTEM BSRWI shall be designed to comply with [40].

# 3 SUPPLIER RESPONSIBILITY

3.1 SUPPLIER shall perform the work in accordance with the requirements of all references in 1.1 of this TS.

3.2 SUPPLIER shall assume sole contractual and total engineering responsibility for the items supplied.

3.3 SUPPLIER's responsibility shall also include but not be limited to:

3.3.1 Resolving all engineering questions and/or problems relating to design and manufacturing.

3.3.2 Providing details as requested, for the main and auxiliary equipment, relating to design and manufacturing.

3.4 Compliance by the SUPPLIER with the provisions of this specification and industry standards does not relieve the SUPPLIER's responsibility to furnish equipment and accessories of a proper mechanical design suited to meet the specified service conditions.

3.5 SUPPLIER is responsible for all coordination with MANUFACTURERS and collections of all details, drawings and data to achieve optimum design and full submission of all documents requested in the specification.

# 4 SUBSEA SEAWATER PUMP TECHNICAL REQUIREMENTS

4.1 Each BSRWI shall comply with all the requirements in [34], [35] and [40].

4.2 The SUBSEA RAW WATER INJECTION SYSTEM shall be intrinsically safe, with its equipment and components designed to mechanically withstand all internal fluid's process conditions according to the RM [34] and the Fluids ET [36], including overpressure, underpressure and other extreme conditions scenarios imposed by produced fluids and fluids injected from topside, also according to the RM [34] and the Fluids ET [36].

4.3 In case the SUBSEA RAW WATER INJECTION SYSTEM design cannot reasonably accommodate the requirements of item 4.2 above, requiring additional levels of protection based on subsea sensors for automatic real-time monitoring, detection, and protective action if an abnormal condition indicating an undesirable event is detected, the SMPS shall be protected by a dedicated SUBSEA SAFETY SYSTEM to provide the SAFETY INSTRUMENTED FUNCTIONS with their respective RISK REDUCTION FACTOR required, according to API RP17V [9] and IEC 61511 [33]. The SUBSEA SAFETY SYSTEM shall be designed and certified as a SAFETY INTRUMENTED SYSTEM (SIS) according to IEC 61511 [33] or more specifically to API STANDARD 17O [10] in the particular case of a HIPPS being required.

4.4 Each SUBSEA RAW WATER INJECTION SYSTEM BSRWI SEPS and the pumping system SEPS shall comply with [39].

4.5 Each SUBSEA RAW WATER INJECTION SYSTEM Control System and BSRWI Control System shall comply [38] and [58].

4.6 Each BSRWI Transducer System and instrumentation shall comply with [58]

4.7 If there is more than one BSRWI in the scope of supply (RM [34]) and they are not exactly the same (including internals) and interchangeable, SUPPLIER shall deliver at least one spare pump RETRIEVABLE MODULE (BSRWI) for each different design.

4.8 MBSRWI and all its components shall fully comply with [9] including the recommended safety devices in annex A. SUPPLIER shall verify if the base cases in [35] and [40] complies with [9] and alert PETROBRAS of any deviation for written approval. At the end of the DETAIL DESIGN STAGE SUPPLIER shall submit a report stating that the SUBSEA RAW WATER INJECTION SYSTEM final design fully complies with [9].

4.9 Each BSRWI shall be individually retrievable (MBSRWI) and comply with all the requirements for a RETRIEVABLE MODULE in [35].

4.10 Each pump shall at least comply with the requirements of [11], [13], [15].

4.10.1 If rigid coupling is applied, any exception in relation to ref. [15] shall be presented for PETROBRAS approval during kick-off meeting of the detailed design phase.

4.10.2 Any exception in relation to ref. [11] and [13] shall be presented for PETROBRAS approval during kick-off meeting of the detailed design phase.

4.11 SUPPLIER shall clearly mark the locations of all connections and identify them on the pump drawing.

4.12 Major rotating parts, such as impellers, balance drums, and couplings, shall be dynamically balanced according to ref. [23], grade G2.5. In addition, the complete rotor shall be dynamically balanced.

4.13 Refs. [34] and [37] shall define how many inlet and outlet wells and flowlines shall be connected to the SRWI SYSTEM, how many multiphase flow meters are required and how many inlet choke valves are required and the position of them.

4.14 Design for Installation:

4.14.1 The MBSRWI shall be designed for installation loads considering minimum speed of 0.7 m/s according to ref. [19]

4.14.2 The MBSRWIs shall be designed for installation loads without heave compensation according to ref. [60].

4.15 Material and Compatibility with Fluids:

4.15.1 Material selection shall be according to [35], [40], [41], [42], [25], [26], [27], [28], [29], [30], [31], [32] and [11] Annexes G and H. Additional requirements for specific pumps on this specification shall be followed:

4.15.1.1 The SUPPLIER shall guarantee and provide evidence during Detail Design Stage that all non-metallic materials in the SRWI SYSTEM in contact with production fluids are compatible with the fluid, O2 content (psl-3G, according to [3]) and with Fluids for Special Operations [57]. High O2 fluids are known to be aggressive to most elastomeric materials. The fluids are described in [36], [40] and [57].

4.15.1.2 The SUPPLIER shall guarantee and provide evidence that all non-metallic materials in the SRWI SYSTEM in contact with control system fluids, compensation fluids and pumps barrier fluids are compatible with those fluids.

4.15.1.3 The SUPPLIER must provide traceable and irrefutable evidence on the compatibility/ageing of the non-metallic materials considering:

*4.15.1.3.1 Representative operational conditions (temperature, pressure, fluids like O2, water, and their concentrations and exposure time of the materials to the scenario/design lifespan).*

*4.15.1.3.2 Chemical products that may be in contact with non-metallic parts, considering representative treatment conditions (temperature, pressure, chemicals their concentrations and exposure time of the materials to these during equipment design lifespan).*

*4.15.1.3.3 Any events that may take place considering equipment operation (for instance, but not limit to, rapid gas decompression – RGD events).*

4.15.1.4 Evidence in 4.15.1.3 must be provided considering representative experimental data based on renowned standards such as ref. **[28]** (thermoplastics) and/or ref. **[27]** (elastomers) or other representative standards, as conservative or more than the ones proposed herein. These results must evidence material overall performance in the application (for instance, but not limited to, compression set, stress relaxation, creeping, mechanical properties, RGD so on and so forth) taking into consideration material within equipment design (for instance, groove fill and squeeze that strongly influence RGD behavior of seals, so on and so forth).

*4.15.1.4.1 A point of attention to be highlighted: the aforementioned standards and others as well (for instance, ref. **[29]**) propose in their scope the so-called "Standard gas mixtures", especially for RGD testing. Supplier must provide evidence on material performance considering bespoke mixtures, i.e., as agreed between interested parties, considering technical specifications. Moreover, if decompression events are expected for the application, those must be evaluated from the material performance point of view (regardless they are thermoplastics or elastomers or their composites) not only using representative scenarios, but also considering representative decompression rates (not necessarily the standardized ones – in ref. **[27]**: 20bar/min shall be compared with the ones in [40], [34], [35]and [36] and the most conservative case shall be considered).*

4.15.2 SUPPLIER shall guarantee and provide evidence that all materials in contact with production fluids in SUBSEA RAW WATER INJECTION SYSTEM Pumps are compatible with the all fluids and $O_2$ content and with Fluids for Special Operations (materials shall be trim HH and psl-3G, according to [3]; If cladded, Ni alloy 625 shall be used with a minimum layer of 3mm. SUPPLIER shall comply with all requirements from [17].). High $O_2$ fluids are known to be aggressive to most elastomeric materials. The internal fluids are described in [36] and[57].

4.15.3 SUPPLIER shall guarantee that internal seals (such as the ones between pump shaft and impellers and between diffusers and casing) are compatible with all internal fluids and $O_2$ content and with Fluids for Special Operations. The internal fluids are described in [36], [40] and [57]. Materials shall be trim HH and psl-3G, according to [3]; If cladded, Ni alloy 625 shall be used with a minimum layer of 3mm. SUPPLIER shall comply with all requirements from [17].

4.15.3.1 The following exceptions shall be submitted for PETROBRAS approval:

*4.15.3.1.1 Internal components in the subsea pumps, if approved by PETROBRAS, MAY be 25%Cr duplex according to ref. [24] (Quality Level I) and limitations by ref. [25] / ref.[17].*

*4.15.3.1.2 Whenever 25%Cr duplex is under cathodic protection, ref. [26] shall be followed.*

*4.15.3.1.3 In case there are dissimilar welds (for example between LAS/C-Mn steel — internally cladded with alloy 625 — and alloy 25% Cr) and subjected to cathodic protection, special consideration shall be taken regarding the welding procedure specification in order to avoid the risk of hydrogen induced stress cracking, therefore, a technical query shall be firstly sent to Petrobras for approval.*

*4.15.3.1.4 F22 MOD MAY be used for the subsea pump, with internally weld overlay with alloy 625 where process is exposed (minimum layer of 3 mm).*

4.15.4 BSRWI painting, anti-fouling and coating shall comply with the requirements of [42], and [47]. Sealing areas and/or surfaces with relative movement shall not be painted.

4.16 Thermal insulation shall comply with all requirements of [35].

4.17 The connector between MBSRWI and SRWIFB shall be a vertical hydraulic connector.

4.18 The following requirements refer vertical hydraulic connectors described in item 4.17:

4.18.1 SUPPLIER shall provide to PETROBRAS:

4.18.1.1 all technical details, assembly and manufacturing drawings of the interface profiles between the hub and connector (hub profile, seal cavity and connector guidance system) in items 4.17 and **Erro! Fonte de referência não encontrada.** (hub and connector). Internal components of the connector may not make part of these drawings, and.

4.18.1.2 use and share authorization letter with the objective of future standardization (license concession for use by PETROBRAS in any purchase purpose). The intellectual property shall remain with the SUPPLIER.

4.18.2 The hydraulic connectors shall be designed for at least 40 locking and unlocking cycles.

4.18.3 The hydraulic connectors shall be designed to guide, support, lock and energize all seals and all fluids flow paths between hub and connector.

4.18.4 The hydraulic connectors pre-load shall be adequate and compatible with internal pressures, forces, shears, bending moments and other stresses during installation and production.

4.18.5 The connectors shall be designed with another hydraulically operated mechanic unlocking system that can replace the primary system if necessary.

4.18.6 The modules shall have in a place easily accessible by ROV one panel with the hydraulic connectors lock line that may be cut in case of emergency unlock necessity. This line shall be painted in red according to [47].

4.18.7 The connectors shall have two easily visible by ROV visual LOCKED/UNLOCKED indicators with 90 degrees between them.

4.18.8 The connectors shall have AX rings and shall have ports for AX rings Seal Tests.

4.18.9 The connectors shall have at least 3mm full clad in all metal x metal sealing areas.

4.19 Soft landing according to ref. [19] and [35].

4.20 MBSRWI shall comply with [35] and be retrievable by cable without a special tool.

4.21 Each BSRWI shall have a Barrier Fluid System according to item 5 of this TS.

4.22 Pumps shall be suitable for continuous operation at full load duty without shutdown for maintenance, for a minimum period of at least 5 years.

4.23 The BSRWI shall be supplied with renewable wear rings.

4.24 Impellers:

4.24.1 Pump design shall ensure that accidental operation in reverse direction (e.g., at start-up or flushing operations) is limited so that no damage can occur to the main equipment. The maximum flushing flowrate shall be defined depending on final geometry, procedures and solids (refer to [36] and [57]) management philosophy during the stages, analysis and meetings described in item 9 of this TS.

4.24.2 SUPPLIER shall offer designs that minimize the number of required impeller stages.

4.25 Mechanical Seals

4.25.1 Mechanical Seals shall comply with ref. [13] considering category 3.

4.25.2 Any exception in relation to ref. [11] and [14] shall be presented for PETROBRAS approval during kick-off meeting of the detailed design phase.

4.25.3 The differential pressure across the mechanical seals in each BSRWI, controlled by subsea barrier fluid control valve, shall be at least the differential pressure specified in item 5.1.6 of this TS).The final value shall be evaluated during the dynamic analyses of the transient behavior of the SUBSEA MULTUPHASE PUMPING SISTEM, wells and production system and BF system according to 5.7.6 and 5.7.7.

4.25.4 The seals shall also be designed to withstand a static differential pressure of at least 1.5 times the maximum differential pressure in service both from barrier fluid to process as well as the other way around.

4.25.5 BSRWI shall employ a seal arrangement with BF leakage only to process side. No barrier fluid leakage to sea shall be accepted.

4.25.6 SUPPLIER shall design BSRWI to ensure a safe temperature at the seal face. This temperature shall be informed to PETROBRAS during DETAIL DESIGN PHASE.

4.25.7 Seal materials shall be the seal MANUFACTURER's recommendation for the service. SUPPLIER may also specify required materials on the datasheets.

4.25.8 All sealing system elements shall be designed to withstand the maximum pressure for different arrangements (serial or single) and for maximum pressure developed by the pump in case of failure in other sealing components, such as the throttle bushing.

4.25.9 SUPPLIER shall inform PETROBRAS the chosen sealing plan according to ref. [13].

4.25.10 SUPPLIER shall verify robustness of seals and barrier fluid system against water hammer phenomena.

## 4.26 Bearings

4.26.1 Hydrodynamic bearing applications shall be designed for the Barrier Fluid System.

4.26.2 The use of rolling element bearings is forbidden. Bearings shall be tilting-pad type.

4.26.3 Bearing housings shall be prepared for proximity probes installation according to ref. [58].

## 4.27 Instrumentation

4.27.1 BSRWI instrumentation, subsea barrier fluid system instrumentation and SUBSEA MOTOR-PUMP TRANSDUCER SYSTEM (SMPTS) shall comply with all the requirements in [58].

## 4.28 Drivers

4.28.1 Each BSRWI shall be driven by an electrical motor and comply with all requirements from SEPS TS [39].

## 4.29 Couplings

4.29.1 Flexible couplings shall comply with ref. [15] and rubber parts shall not be used.

4.29.2 If rigid couplings are used the motor-pump and coupling assembly shall be included in all rotordynamic analysis in this TS.

## 4.30 Pressure Vessels

4.30.1 All Pressure Vessels within Pump Package shall be designed according to [16].

## 4.31 Shaft

4.31.1 Shaft surface preparation in the probe area and calibration to the installed probe area shall be performed in accordance with ref. [18] (25% of the maximum allowed peak-to-peak vibration).

## 4.32 Inlet Storage Component and Liquid Extraction Unit:

4.32.1 The MBSRWI shall have an Inlet Storage Component according to [9].

4.32.2 The MBSRWI shall have a Liquid Extraction Unit outlet according to [9].

4.32.3 SUPPLIER shall submit for PETROBRAS approval a report with full analysis and simulation of the design and ability of both Inlet Storage Component and Liquid Extraction Unit to handle all operational conditions of pump operation presented in [36] and [40]. This report shall present CFD and process analysis relating flow conditions in Inlet Storage Component and pump suction for all operational conditions.

# 5 PUMP BARRIER FLUID SYSTEM MINIMUM TECHNICAL REQUIREMENTS

## 5.1 General Construction Requirements

5.1.1 SRWI BARRIER FLUID SYSTEM shall be designed to withstand and allow EBSRWI safe operation in all conditions and parameters described in RM [34] and Fluids TS [36].

5.1.2 SUBSEA RAW WATER INJECTION SYSTEM Barrier Fluid System shall comply with all the requirements in [34], [35] and [40]

5.1.3 Barrier Fluid HPU power and utilities consumption shall be within the provided capacity of the FPSO according to ref. [59].

5.1.4 SRWI BARRIER FLUID SYSTEM shall follow each requirement, stage, step and analysis in TS [35], including STEADY-STATE AND DYNAMIC SIMULATIONS, RISK ASSESSMENT, DETAIL DESIGN, MATIC STAGE, INTEGRITY MANAGEMENT PROGRAM AND DECOMISSINING.

5.1.5 At least 3 (three) oil-based barrier fluid options or at least 2 (two) water-based barrier fluid options easily available in the market shall be qualified for the Pumps and motors sets (BSRWI) before the first EBSRWI is delivered to PETROBRAS according to item 5.8 of this TS.

5.1.5.1 Those barrier fluid options shall also be compatible between themselves allowing mixtures during operation.

5.1.5.2 SUPPLIER to confirm that all barrier fluid options are non-flammable and have flash point above the minimum temperature stated in 4.2.

5.1.6 The Barrier Fluid System shall be designed to seek a differential pressure set point across the mechanical seals in each BSRWI, controlled by subsea barrier fluid control valve, of 40 (forty) bar (refer to 4.25.3) above the worst-case differential pressure between barrier fluid and process fluid. The final value shall be evaluated together with the dynamic analysis of the transient behavior of the SUBSEA RAW WATER INJECTION SYSTEM and BF system according to 5.7.6 and 5.7.7 of this TS. Barrier fluid pressure shall be kept higher than process pressure in all

operational conditions detailed by SUPPLIER to fully fulfill SUBSEA RAW WATER INJECTION SYSTEM safety and performance requirements.

5.1.7 The Barrier Fluid System shall be designed to allow normal continuous operation even if barrier fluid consumption is at least 10 (ten) times the regular designed consumption.

5.1.8 The Barrier Fluid System shall be designed to supply BF subsea and protect the pump even if the topside part of the system is unavailable for 48 hours.

5.1.9 SUPPLIER shall design the Barrier Fluid HPUs to comply with the SRWI SYSTEM needs, considering one dedicated Barrier Fluid HPU for each BSRWI (unless otherwise stated in [34]). Alternatively, SUPPLIER shall propose an optimized solution for PETROBRAS approval.

5.1.9.1 For any Barrier Fluid HPU configuration, the barrier fluid consumption shall be measured individually for each BSRWI.

5.1.10 Topside Barrier Fluid HPU shall supply constant pressurized hydraulic barrier fluid for operation of the SRWI SYSTEM.

5.1.11 The HPUs shall supply the barrier fluid through each umbilical leading from topside facility to the subsea consumer (2 veins in each for each pump; total: 4 per umbilical).

5.1.12 A set of spare parts, defined by the SUPPLIER, shall be delivered to guarantee at least 2 (two) years of continuous operation for each Barrier Fluid HPU including the operational Barrier Fluid.

5.1.13 To comply with the SRWI SYSTEM needs, SUPPLIER shall design 2 (two) dedicated Barrier Fluid Subsea Assemblies (MFB) for each BSRWI (one in regular operation and one redundancy per BSRWI). Those assemblies shall be easily removed topside.

5.1.13.1 These Barrier Fluid Subsea RETRIEVABLE MODULEs (MFB) shall contain all wearable components of the subsea barrier fluid system. As a minimum it shall contain the pressure control feed/dump valves and filters. The SUPPLIER shall submit for PETRBRAS approval which components shall be part of the MBSRWI and which shall be part of the MFB.

5.2 Barrier Fluid system shall be designed to comply with NAS 1638 Class 6 or better. (Similar to ISO 4406 Code 16/12 or better and SAE AS 4059 class 6B-F).

5.3 If the MFB for different EBS in the scope of supply are exactly the same (including internals) and interchangeable, SUPPLIER shall deliver at least one spare Barrier Fluid Subsea RETRIEVABLE MODULE for each set of up to 3 EBS (unless otherwise stated in [34]).

5.4 If the MFB in the scope of supply are not exactly the same (including internals) and interchangeable, SUPPLIER shall deliver at least one spare MFB for each design. If there are more than 3 EBS of the same design, SUPPLIER shall deliver at least one spare Barrier Fluid Subsea RETRIEVABLE MODULE for each set of up to 3 EBS of the same design (unless otherwise stated in [34]).

5.5 It shall be possible to switch which of the two MFB in the same EBSRWI is active with the BSRWI in place. This switch shall be both remotely and ROV actuated (unless otherwise stated in [34]).

5.6 Barrier Fluid HPU / Tanks / Topside Accumulators

5.6.1.1 Topside Barrier Fluid HPU shall supply constant pressurized hydraulic barrier fluid for operation of the SRWI SYSTEM.

5.6.1.2 SUPPLIER shall ensure that the area around the pump topside utilities PACKAGE has enough clearance for maintenance. SUPPLIER shall create a reserved area on the 3D model to avoid installation of any other equipment or accessory in this area.

5.6.1.3 The Barrier Fluid HPUs shall be operated through a central Control Panel Located in a separated area.

5.6.1.4 The Barrier Fluid HPUs unit shall be designed and manufactured to be installed in the FPSO and for offshore lift. It shall be designed to offshore environment and be able to handle sea environment and sea conditions according to ref.[59].

5.6.1.5 If the Barrier Fluid is oil based, the Barrier Fluid HPUs shall have a purifier unit to deal with water contamination of the fluid.

5.6.1.6 The Barrier Fluid HPUs shall carry an overhead weather protection that shall also be rigid enough to support falling objects of at least 100 kg.

5.6.1.7 The scope of supply includes design, manufacturing, testing, inspection, packing, supply of goods, services and documentation for the Barrier Fluid HPUs according to [35].

5.6.1.8 Total System accumulator design capacity shall have enough spare duty pressure for a shut in/ESD situation even in case of Barrier Fluid HPUs power not available.

5.6.1.9 The Barrier Fluid HPUs shall be built in AISI 316L stainless steel material.

5.6.1.10 Double block and bleed isolation from system pressure shall be implemented as a minimum for all components designed for maintenance during operation of the Barrier Fluid HPUs.

5.6.1.11 All internal components within the Barrier Fluid HPUs shall be easily accessible for maintenance without the need to remove other parts of the system.

5.6.1.12 The Barrier Fluid HPUs shall handle/store Barrier Fluid of stringent quality requirements and of high cleanliness level. Extreme care shall be taken to ensure maximum cleanliness is achieved during design, manufacturing, testing and operation.

5.6.1.13 The Barrier Fluid HPUs shall be designed and manufactured for minimum dirt entrapment. Installation and assembly of each unit shall be done with the best workmanship and all its components shall have the minimum cleanliness level verified when installed. Flushing of Barrier Fluid HPU/systems/circuits is required, and procedures shall be submitted by SUPPLIER for Petrobras approval.

5.6.1.14 The maximum noise level of the HPU Module with pumps running shall be 80 dB measured at a maximum of 1 m from the Barrier Fluid HPU Module.

5.6.1.15 Barrier Fluid HPU tanks venting shall be on top of each tank. System venting connections shall be fitted at elevated spots with easy access.

5.6.1.16 All instrument and power cables shall be properly supported/routed by means of cable trays leading from the component to dedicated junction box(es).

5.6.1.17 Stainless steel straps with plastic overlay shall be applied on cables. Edge protector of typically “Volvo list type” on trays shall be applied on all sharp edges.

5.6.1.18 The Barrier Fluid HPU shall be operated through a Central Control Panel receiving operational signals from the HPU and dedicated subsea instrumentation. (Pressure transmitter(s)).

5.6.1.19 Each Barrier Fluid HPU shall measure the individual barrier fluid consumption of each BSRWI.

5.6.1.20 The Barrier Fluid HPU framework shall include and support the Barrier Fluid HPU tanks, components, tubing and instrumentation. Pumps, motors and accumulators shall be rigidly supported and bolted.

5.6.1.21 The Barrier Fluid HPU instrumentation shall not be directly supported by the tubing but shall have its own support into the Barrier Fluid HPU frame. Unobstructed access to the Barrier Fluid HPU components and instruments for the purpose of easy observation and maintenance is required.

5.6.1.22 The Barrier Fluid HPU tanks shall include a top cover lid/hatch sized for internal inspection and for access to the internals of the tanks.

5.6.1.23 The Barrier Fluid HPU shall be dimensioned and constructed to meet requirements for offshore lift. DNV regulation 2.7-3 shall be applied. Lifting gear for the purpose of offshore lift shall be temporarily fixed to the Module roof for easy pick up for lifting. Suitable overhead lifting/hook up points for the Barrier Fluid HPU Unit shall make part of the Barrier Fluid HPU frame and shall be documented according to required lifting.

5.6.1.24 The Barrier Fluid HPU shall have pockets for fork lifting.

5.6.1.25 The Barrier Fluid HPU pumps shall be installed in a way that pump inlet suction shall be located at a minimum of 100 mm above the bottom of the tank to avoid eventual sediments being sucked by the pump during operation.

5.6.1.26 Each Barrier Fluid HPU shall have two separate fluid reservoirs, one system tank and one storage tank. The tanks shall be rectangular with flat top and sloped bottom for easy drainage. The fluid reservoirs shall be sized according to SUPPLIER standard.

5.6.1.27 The reservoirs are atmospheric and ventilated through a breathing filter fitted directly on top of the tank. The filters shall be capable of removing a limited level of humidity from the tank atmosphere. Per design, the reservoirs shall be dimensioned to take a minimum over pressure of 0.1 barg.

5.6.1.28 Each fluid reservoir shall have at least one individual drain. Drain outlet shall be flushed with reservoir bottom lower part for maximum drainage. Each individual drain outlet shall have its own isolating valve before being assembled to one common drain interface at the Module platform board interface.

5.6.1.29 Design shall foresee easy and ergonomic access to all valves, as well as to drains and vents and for other routine operations such as exchanging filters and taking samples.

5.6.1.30 For fresh barrier fluid filling into the storage tank only, a dedicated pneumatic barrel Pump shall be included. The barrel pump is permanently fitted to a filling filter on top of the storage tank through a flexible rubber hose. Similarly, the barrel pump shall be provided with another plastic hose for shipboard pneumatic air supply.

5.6.1.31 The filters of Barrier Fluid HPU shall be without bypass. Each filter or filter pair shall be fitted with a differential pressure transmitter. The system shall be sized to operate at maximum differential pressure. Replacing high pressure filter elements shall not interrupt normal operation of the Barrier Fluid HPU and isolation shall be provided for safe filter exchange. Easy access to filter(s) barrel(s) is required as well as access space for a spanner during the unscrewing of the barrels.

5.6.1.32 Topside accumulators required for the HPU operation shall be located within the boundary of the Barrier Fluid HPU frame. Accumulators shall be fitted with filling connection(s) suitable for the dedicated filling kit supplied and shall be located for convenient access. The filling nozzle shall be identified for the actual accumulator.

5.6.1.33 A Nitrogen filling kit (with pressure indicator and isolation valve that shall be screwed to the mating accumulator coupling) shall be included.

## 5.6.2 Instrumentation

5.6.2.1 All instrumentation shall be assembled for easy observation and access. Instrument block and bleed valves shall be fitted directly to actual instruments with minimum tube extension in order to avoid air pockets.

5.6.2.2 Standard instrumentation to Barrier Fluid HPU:

*5.6.2.2.1 Pressure Indicating Smart Transmitters (PIT) (4/20 mA, 24 V), Smart type based on HART protocol with local display.*

*5.6.2.2.2 Differential Pressure Indicating Transmitters (PDIT) (4/20 mA, 24 V) Smart type based on Hart protocol with local display.*

*5.6.2.2.3 Tank level Transmitters (LT) based on pressure transmitter reading. (4-20 mA, 24 V) Smart type based on Hart protocol with remote indication only.*

*5.6.2.2.4 Level gauge (LG). Magnetic flags, changing color as fluid level rises.*

*5.6.2.2.5 Level indicating plate giving level in % and the correspondence in liters.*

*5.6.2.2.6 Flowmeter to measure barrier fluid consumption for each pump connected to Barrier Fluid HPU.*

*5.6.2.2.7 Barrier Fluid cleanliness analyzer or particle counter to verify the fluid output from the purifier required in 5.6.1.5. If the fluid is oil-based, water content shall be measured.*

*5.6.2.2.8 Pressure Indicating Gauge(s) visor of 100 mm, span 0-500 barg. SUPPLIER shall propose the optimized span for PETROBRAS approval.*

*5.6.2.2.9 Temperature Indicating gauge(s) visor of 100 mm, span: 0 °C to 120 °C.*

5.6.2.3 NPT connections of any kind shall be avoided. BSPP, UNF w/soft seal or Twin Ferrule compression fittings shall be applied. All connections shall be prepared to withstand vibration (flow or dynamic equipment induced or external from FPU)

5.6.2.4 Fluid sampling points shall carry a tube end extension for easy sampling with good access for a sampling bottle.

5.6.2.5 All instrument free air bleed connections shall be fitted with a safe connection with adequate destination.

5.6.3 Manually operated valves:

5.6.3.1 Duty isolation valves shall be: On/off ball valves

5.6.3.2 Fluid sampling valves shall be Needle valves

5.6.3.3 Block and Bleed valves shall be Ball valve for isolation/block, needle valve for bleed

5.6.3.4 Safety valves:

5.6.3.5 The Barrier fluid HPU is fitted with Pressure Relief/Pressure Safety valves. The valves shall be state of the art valves constructed for repeated operations without the need of recalibration.

*5.6.3.5.1 All the Pressure Relief/Pressure Safety and normal valves shall be qualified by SUPPLIER. The valves shall be calibrated to a maximum set point according to HPU operational and design pressure.*

*5.6.3.5.2 Selection and sizing shall be in accordance with refs. [20] and [21]. Valves intended for atmospheric tanks shall comply with ref. [21].*

*5.6.3.5.3 PSVs shall have upstream and downstream block valves.*

*5.6.3.5.4 The blocking valves of the PSV shall always remain open when installed, even if it is not in operation. The blocking valves can only be closed to allow the PSV to be removed for maintenance. A mechanical interlock device shall be provided for the block valves.*

*5.6.3.5.5 The pressure and diameter classes of the inlet and outlet flanges of the PSVs shall be in accordance with the tables of item 11 of ref. [20] for the specified orifice. The pair of inlet and outlet flanges shall be chosen to provide the desired set pressure at the desired relief temperature. If the pressure class of the inlet or outlet flange is greater than the pressure class of the line that connects to it, it shall be revised to the same PSV flange pressure class.*

*5.6.3.5.6 Balanced bellows valve design shall be considered for variable back pressures when the variation exceeds 10% of the set pressure.*

### 5.6.4 Special Barrier Fluid HPU Features Requirements

5.6.4.1 Diagonally located earth bonding connections size M12 shall be fitted on Barrier Fluid HPU frame bottom frame.

5.6.4.2 Each motor shall have their own dedicated earth connection to the Barrier Fluid HPU frame.

5.6.4.3 All bleed connections (plugged) on instrument manifolds and block and bleed valves shall be fitted with an interface of the type of bleed or purge valve with a hose adaptor extension.

5.6.4.4 2 cubicles containing motor starters and analog/digital instrument cable terminations shall be located on the HPU frame within frame boundaries. Preferred location is on the instrument platform.

5.6.4.5 Local start and emergency stop combined button shall be fitted close to each motor.

### 5.6.5 Redundancy and Maintenance for Barrier Fluid HPU

5.6.5.1 All pressure instruments and components requiring regular maintenance, also involving removal or on the spot calibration must be designed for these operations to happen without having to shut down the pressure system and shall be fitted with block bleed/block valves.

5.6.5.2 Hydraulic Pressure System lines shall be fitted with duty and back up pumps.

5.6.5.3 System line(s) dual filter inserts shall be replaceable during operation.

5.6.5.4 One local pressure gauge and pressure transmitter on system line(s) and on duty line(s) shall be fitted with block bleed block valves for on-the-spot maintenance and calibration.

5.6.5.5 Reservoir Level Transmitters for remote reading, including local magnetic level gauge. The level transmitter shall be a pressure transmitter (only local indication is not acceptable) and shall be separate from level gauge.

### 5.6.6 Interface / Marking / Labelling / Tagging

5.6.6.1 The Hydraulic interface connections, inlet and outlet, for external hook up shall be terminated into a bulkhead plate or manifold rigidly supported by the HPU frame.

5.6.6.2 All open-ended connections shall be sufficiently sealed and plugged for avoiding the ingress of dust and/or humidity.

5.6.6.3 Instrument cable shall be marked according to SUPPLIER Cubicle termination drawing.

5.6.6.4 Instruments and components shall be tagged /marked according to tags approved by PETROBRAS. The tag is an engraved stainless-steel plate attached to the instrument with a stainless-steel wire. Letters shall be at least 5 mm high.

5.6.6.5 Local label shall be applied for all main components / instruments requiring attention. The label shall be resistant plastic plate screwed to the instrument support. Letters shall be at least 15 mm high and shall be black letters on a white background.

5.6.6.6 Main components and instruments within the HPU shall be labelled with its operative function, tag number and serial number.

5.6.6.7 Operational instruction tag shall be included on 3-way selector valve for “filling/transfer”, “circulation” at storage tank.

5.6.6.8 Barrier Fluid HPU Fabrication Data Sign shall be fitted on an easy-to-read location.

5.6.6.9 All external interfaces requiring tie up from platform facilities shall be marked/identified according to hydraulic schematic. Black letters of at least 5 mm high on white background shall be used. Identifications, notices and warnings labels shall be approved by PETROBRAS. The main text shall be in Brazilian Portuguese and below 1mm smaller letters with the same text in English shall be present. Red letters with yellow background shall be used.

5.6.6.10 ID marking of Barrier Fluid HPU sampling points shall be tagged with black letters on white background.

5.6.6.11 PSVs shall in addition to tag number and certificate ID number be labelled with PSV set point in engraved stainless-steel plates with black letters.

### 5.6.7 Design loads

5.6.7.1 Dimensional Analysis/calculations shall be carried out and a Verifying Report issued for PETROBRAS approval. Calculations shall as a minimum identify and verify the following:

*5.6.7.1.1 Barrier Fluid HPU framework with tanks against given both Platform accelerations and transport loads.*

*5.6.7.1.2 Barrier Fluid HPU Module lifting and lifting gear certification based on offshore lift with HPU tanks 50% filled with fluid.*

Note: The dimensional load based on the HPU filled with barrier fluid shall be used for added safety. Normally the HPU is lifted empty.

### 5.6.8 Surface Protection

5.6.8.1 SUPPLIER´s standard paint system may be considered for individual components. Painting procedure and color code shall be sent beforehand at DETAIL DESIGN STAGE (according to [35]) for PETROBRAS approval.

## 5.7 Barrier Fluid Subsea RETRIEVABLE MODULE – Subsea Barrier Fluid Control Valve

5.7.1 The MFB shall be redundant (2 Barrier Fluid Subsea RETRIEVABLE MODULEs per BSRWI), and each module shall be individually retrievable (individual modules for each barrier fluid control valve).

5.7.2 Each MFB shall comply with RETRIEVABLE MODULEs requirements from [35].

5.7.3 Each Subsea Barrier Fluid Control Valve shall be placed in a MFB together with all subsea barrier fluid system instruments, filters and equipment required for normal pump operation.

5.7.4 Each Subsea Barrier Fluid Heat Exchanger shall be placed in a RETRIEVABLE MODULE (in the MFB or in the pump RETRIEVABLE MODULE — MBSRWI).

5.7.4.1 SUPPLIER shall submit for PETROBRAS approval full analysis and simulation of the pump and barrier fluid circuit heat transfer including CFD simulations.

5.7.5 Each Subsea Barrier Fluid Filter shall be placed in a RETRIEVABLE MODULE (in the MFB or in the pump RETRIEVABLE MODULE — MBSRWI).

5.7.6 SUPPLIER shall submit for PETROBRAS approval full analysis and simulation of the response time of the barrier fluid system upon pump start-up, pump normal stop, pump emergency shutdowns and pump ramp-up considering field information provided by PETROBRAS and dynamic simulation studies of SUBSEA RAW WATER INJECTION SYSTEM operation.

5.7.7 This analysis is part of STEADY STATE and DYNAMIC SIMULATION according to [35].

5.7.8 Barrier Fluid dynamic and Barrier Fluid System parameters shall be tuned during COMISSIONING PHASE (MATIC) according to [35].

## 5.8 Barrier Fluid Qualification Assurance

5.8.1 SUPPLIER shall provide the Barrier Fluid Qualification Assurance Report, as per [8], with description and evidence of TRL 4, as per [8], and TRC C, as per [7],

achievement throughout the Barrier Fluid qualification process as part of SUBSEA RAW WATER INJECTION SYSTEM Detail Design.

5.8.2 PETROBRAS, as its own discretion and during Detail Design and also during all other project stages, may ask for a dataroom to verify any document listed in the Barrier Fluid Qualification Assurance Report.

5.8.3 Barrier Fluid Qualification Assurance Report shall report, as a minimum, the following:

5.8.3.1 Barrier Fluid qualification test program goals, requirements and acceptance criteria summary including the complete list of test procedures and test report documents with document number, title, revision and emission date.

## 5.9 Technical Documentation

5.9.1 A complete individual Technical Documentation of the Barrier Fluid HPU shall be delivered to PETROBRAS including recommendation to inspections and maintenance routine.

5.9.2 An individual Barrier Fluid HPU Operational and Maintenance Manual shall be delivered to PETROBRAS (versions in English and Brazilian Portuguese language).

5.9.3 An individual Barrier Fluid HPU power and topside and subsea utilities consumption datasheet shall be provided. This datasheet shall present maximum and minimum expected values and safety limits.

5.9.4 The 3D Model in 5.6.1.2 shall be delivered to PETROBRAS in a software file format in accordance with the requirements in [35] and [52] and in a PDF report.

5.9.5 Besides the individual documents, Barrier Fluid documentation shall follow all requirements in [35] and [52].

5.9.6 All information present in the individual documents in 5.9 shall also be part of SUBSEA RAW WATER INJECTION SYSTEM Documentation according to [35] and [52].

# 6 FAT — FACTORY ACEPTANCE TEST

6.1.1 The FATs shall be witnessed by PETROBRAS.

6.1.2 SUPPLIER shall provide FAT test reports up to 30 days after their execution.

6.1.3 For the Factory Acceptance Test (FAT), the PACKAGER / MANUFACTURER shall make preliminary test to ensure that all parts of the equipment are operating satisfactorily prior to the arrival of the PETROBRAS's representatives. SUPPLIER shall advise PETROBRAS of the test schedule before the planned test. Unless otherwise agreed, witnessed FATs require written confirmation of a successful preliminary test.

6.1.4 The dates and order of the tests in the FAT shall be submitted for PETROBRAS approval at least 60 days before the first test.

6.1.5 Acceptance of the FAT will not be considered as the final acceptance test of the equipment.

6.1.6 If it is found necessary to dismantle or change any equipment during a test, because of malfunction, the test may then be invalidated, and a full test shall be required after the repair of the fault or after any change.

## 6.2 BSRWI FAT Conditions

All tests in this section (6) except the one in 6.2.5 shall be performed for each final pump with the respective final subsea electrical motor with water. All expected operating points presented on the references [40] shall be verified during the FAT, emulating expected field fluid properties and operation conditions – respecting total flowrate and pump differential pressure required for each of those conditions.

6.2.1 SUPPLIER shall be responsible for providing facilities, infrastructure, test fluids, power and utilities.

6.2.2 The final BSRWI subsea operational monitoring systems according to [58] shall be tested on the FAT.

6.2.3 Fourteen days before each test, SUPPLIER shall send to PETROBRAS the expected leakage flowrate across the seals for each of the transients and operational points expected in the respective test procedure in relation to the temperatures, pressures, speeds and number of hours for each fluid used in the test.

6.2.3.1 After any item of the final subsea monitoring system is tested in the FAT, it shall not be changed before final subsea installation.

6.2.4 Motors FAT tests shall be in accordance with [39].

6.2.5 Each BSRWI shall be hydrostatic tested according to [11] and [16].

6.2.6 The following process steady state conditions that shall be met before each rotordynamic test and each test running the pump begin: when the suction pressure, suction temperature and suction total flow rate is stable for, at least, 5 (five) minutes, considering the reference deviation of each variable as below:

*6.2.6.1.1 Pressure = +/- 3.0 bar*

*6.2.6.1.2 Temperature = +/- 1.0 °C*

*6.2.6.1.3 Volumetric flow rates = +/- 3.0%*

*6.2.6.1.4 Density = +/- 3.0%*

*6.2.6.1.5 GVF = 0%*

6.2.6.2 For all tests, the operational variables raw data must be recorded at maximum interval of 0.5 second.

## 6.3 FAT – Test Program

6.3.1 Part A: Performance Pump curves (including pump efficiency and power curves) by handling water and air - sweep the pump envelope (5 points each) at minimum, intermediate and maximum pump speed.

6.3.1.1 This test shall be Witnessed by PETROBRAS

6.3.2 Part B (24-hour Endurance Test): Establish a continue cumulative total time of 24 hours running in an operational point to be agreed during performance tests.

6.3.2.1 This test shall be Witnessed by PETROBRAS

6.3.3 If a rigid coupling is used between motor and pump, during all FATs, proximity probes shall be installed on both the electric motor and the pump and monitored during the FAT.

6.3.3.1 At least 8 probes (X-Y pairs for DE and NDE for both pump and motor sides) shall be installed.

6.3.3.2 If either final motor or pump subsea configuration does not consider rotor vibration monitoring, temporary non-subsea probes may be used during FAT.

6.3.3.3 The same acceptance criteria for MRT steps shall apply to the motor and pump vibration probes.

6.3.4 The following data shall be available, recorded and printed (or plotted) during (Mechanical Run Test) MRT and Performance Test:

*6.3.4.1.1 all vibration and phase signals shall be recorded during the whole test.*

*6.3.4.1.2 unfiltered & filtered vibration amplitude and phase angle X speed diagrams (bode and polar plots).*

*6.3.4.1.3 orbits and shaft centerline plots.*

*6.3.4.1.4 frequency spectra taken during relevant phenomena.*

*6.3.4.1.5 "waterfall" cascade plots for rotor startup and coast down.*

*6.3.4.1.6 raw data table for the whole test (instant values of all measured variables printed in columns versus elapsed test time on lines).*

*6.3.4.1.7 slow roll run out (and phase angle) measurements taken during test.*

6.3.5 transient data trend plots for the whole test (graphs with all measured variables shown in several trend lines, versus elapsed test time).

6.3.6 Connection Test shall be performed to guarantee that the MBSRWI complies with the installation requirements, orientation and stresses for the connection. SUPPLIER shall propose the procedure for PETROBRAS approval.

6.3.7 Mechanical Run Test (MRT) shall be done with water at maximum speed according to items 8.3.4.2.1 and 8.3.4.2.2 from [11] for at least 4 hours in an operational point that shall represent the most critical rotordynamic condition, as defined by the Lateral Analysis Report considering actual fit-in clearances, and shall be approved by PETROBRAS during Detail Design Stage within the range in [40].

6.3.7.1 During Mechanical Run Test the highest bearing surface metal temperature shall not exceed the maximum design temperature at maximum continuous speed.

6.3.7.2 During Mechanical Run Test the bearing metal surface temperature shall be continuously recorded. This temperature can be inferred from barrier fluid temperature and the model used shall be presented with the test results.

6.3.7.3 Casing and rotor vibration shall not exceed the limits of ref [14] during the entire Mechanical Run Test, except for the speed transients.

6.3.7.4 Barrier fluid inlet temperature shall be varied across the range permitted in the pump operating manual. A method to enable barrier fluid temperature variation shall be proposed in the test procedure. The test procedure shall be submitted for Petrobras approval. Barrier Fluid instant flowrate shall be measured during the whole MRT duration.

*6.3.7.4.1 Barrier fluid conditions change test shall be done during the four-hour Mechanical Run Test, but not before all test parameters and variables are considered stable or steady enough to proceed. This test does not constitute a waiver of the other specified test requirements. The barrier fluid conditions change shall be held for a minimum of five minutes after temperature stabilization.*

6.3.8 Performance Test shall be performed with water according to [11] at design conditions and comply with ref. [40].

6.3.8.1 The requirements in 6.2.6 shall be fulfilled.

6.3.8.2 At least 5 points operational points shall be tested at each speed:

*6.3.8.2.1 Minimum Continuous Stable Flow (MCSF)*

*6.3.8.2.2 Maximum Allowable Operating Flow*

*6.3.8.2.3 Best Efficiency Point*

6.3.8.3 The above-mentioned points shall be tested at minimum and maximum operating speeds. For each speed, the tested Minimum Continuous Stable Flow shall not deviate by more than +10% from the predicted MCSF.

6.3.8.4 Additionally, the Rated Point, as specified by PETROBRAS, shall also be tested. At this point the following acceptance criteria shall apply:

*6.3.8.4.1 Pump head – as measured and corrected to the final design conditions – shall not deviate by more than* $\pm$ 3% *from specified conditions*

*6.3.8.4.2 Power consumption, as measured and corrected to final design condition, shall not exceed a predicted value. This value shall be informed by SUPPLIER complying with the FPSO power availability. See ref. [59].*

6.3.8.5 The measured overall shaft vibrations during the entire Performance Test including slow roll runout shall not exceed item 8.2.2.2 from ref [14].

6.3.9 Impact tests (Experimental Modal Analysis) shall be performed during the FAT to validate the Unit`s predicted structural natural frequencies. All relevant structural natural frequency within the range of 0% to 120% the Maximum Continuous Speed must be identified and taken into account in the Lateral Analysis Report. If any of the identified natural frequencies deviate from predictions by more than 10% or 1 Hz, whichever is greater, the Lateral Analysis Report shall be reviewed accordingly.

6.3.10 24-hour Endurance Test (see section 6.3.2)

6.3.10.1 A 24-hours Endurance Test shall be run with water). Petrobras shall approve test procedure and operational points.

6.3.10.2 The 24-hours Endurance Test shall be performed with the pump running for at least 24 hours after flow stabilization. The test procedure shall be submitted for Petrobras approval. Barrier Fluid instant flowrate shall be measured during the 24-hour Endurance Test.

6.3.10.3 The BSRWI motor-pump assembly casing shall not be opened after the 24h Endurance test. If the pump is opened, this test shall be run again before final installation.

6.3.11 All other FAT requirements from [35] and [40].

## 6.4 BF HPU Factory Acceptance Test

6.4.1 SUPPLIER shall verify the completion of the unit prior to performance of FAT. SUPPLIER will forward Mechanical Completion Dossier including all relevant Mechanical Completion checklists for completion by SUPPLIER.

6.4.2 Acceptance level for the unit shall, as a minimum, include the following:

6.4.2.1 Mechanical Completion Inspection.

6.4.2.2 Flushing of tubing to NAS 1638 Class 6 or better. (Similar to ISO 4406 Code 16/12 or better and SAE AS 4059class 6B-F).

6.4.2.3 Pressure test to 1,5 x design pressure for min. 30 min. WITNESS point.

6.4.2.4 Limited functional test at sub-contractor workshop (FAT).

6.4.2.5 24-hour leakage test.

6.4.2.6 Accumulator stick/slip test. Recorded result.

6.4.2.7 Weighing and dimensional verification of the completed assembly.

6.4.2.8 All testing shall be performed according to procedures approved by PETROBRAS.

6.4.2.9 A witnessed NPSH test according to [11] shall be performed for each pump in each BF HPU unless positive displacement pumps are used.

6.4.2.10 Sound Level test according to [11] shall be performed for each pump in each BF HPU.

6.4.2.11 All other FAT requirements from [35].

## 6.5 BF Fluid System Factory Acceptance Test

6.5.1 SUPPLIER shall verify the completion of the unit prior to performance of FAT. SUPPLIER will forward Mechanical Completion Dossier including all relevant Mechanical Completion checklists for completion by SUPPLIER.

6.5.2 Acceptance level for the unit shall, as a minimum, include the following:

6.5.2.1 Mechanical Completion Inspection.

6.5.2.2 Flushing of tubing to NAS 1638 Class 6 or better. (Similar to ISO 4406 Code 16/12 or better and SAE AS 4059class 6B-F).

6.5.2.3 Pressure test to 1,5 x design pressure for min. 30 min. WITNESS point.

6.5.2.4 Limited functional test at sub-contractor workshop (FAT).

6.5.2.5 24-hour leakage test.

6.5.2.6 Accumulator stick/slip test. Recorded result.

6.5.2.7 Weighing and dimensional verification of the completed assembly.

6.5.2.8 All testing shall be performed according to procedures approved by PETROBRAS.

6.5.3 All other FAT requirements from [35].

# 7 PUMPING SYSTEM EFAT — EXTENDED FACTORY ACEPTANCE TEST

7.1 The requirement in this section 7 shall be confirmed during the Bidding Phase

7.2 All tests in this section (7) shall be performed with water.

7.3 SUPPLIER shall be responsible for test facilities, infrastructure, test fluids, power and utilities.

7.4 The EFAT for each MBSRWI in the SUBSEA RAW WATER INJECTION SYSTEM scope of supply (ref. [34]) shall be performed with the final MBSRWI, the final Control HPU, the final Control System, the final BFHPUs, the final MFB, the final Pump and Motor and the final SEPS system.

7.5 If there are pumps in parallel or series in the project, the EFAT shall test those arrangements. This requirement shall be confirmed during the Bidding phase.

7.6 The procedures that make up the Pumping System's EFAT shall ensure the following:

7.6.1 System's functional and operational capabilities

7.6.2 Interface configurations

7.6.3 Sub-systems adequate operation under specified conditions

7.6.4 Sub-systems' when used in "wet conditions"

7.6.5 Interface between Unit and loose items

7.6.6 Test and Verify Control Logic and Protection

7.6.7 Testing of long step-out systems including start-up, trip functions, load changes, load envelope and current limiter function

7.6.8 Pressure Integrity

7.6.9 Fluid and system cleanliness

7.6.10 Emergency stop

7.7 The EFAT shall be performed in a wet pit test loop with the following configuration:

7.7.1 The Subsea Seawater Pump (BSRWI) with final motors and VFDs and process

control system, including protection, valves and load sharing systems.

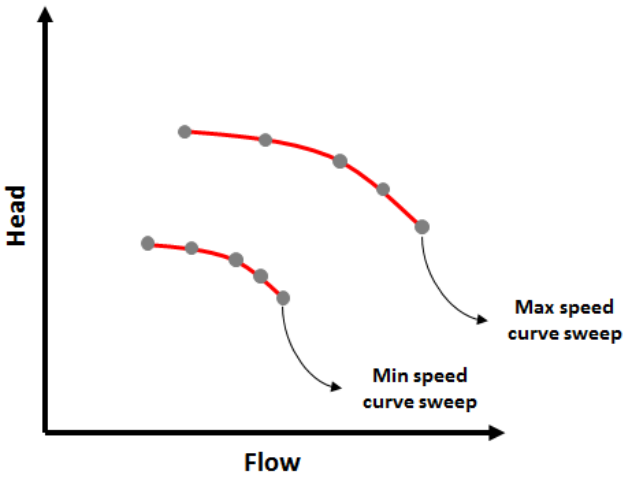
7.7.2 The final Control HPU, BFHPU, Barrier Fluid System, Long Step-Out Power Supply system and the final SEPS system.

7.7.3 The final MBSRWI

7.8 Barrier Fluid instant flowrate for each BSRWI shall be measured during the EFAT.

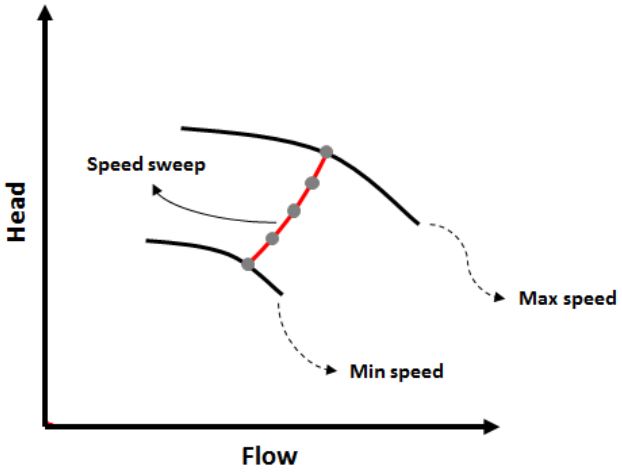
7.9 The following performance evaluations shall be carried out considering the fluids and operational conditions presented on [40], considering a pump operational envelopesuction pressure of 20 barg .

7.9.1 Pumping system arrangement performance curve sweeps at both minimum, intermediate and maximum operational speeds. Each curve sweep must include at least 5 stable operating points, considering the same stability criteria from the FAT Performance tests (item 6.3.8). These points shall be approved by PETROBRAS during detailed design phase.




*EFAT Performance evaluation – Curve Sweeps*

7.9.2 One single speed sweep from minimum to maximum operational speed following the Best Efficiency Points including at least 5 stable points in five different speeds, considering the same stability criteria from the FAT performance tests (item 6.3.8).




*EFAT Performance evaluation – Speed Sweep*

7.9.3 One system emergency stop test shall be performed with each pump in the scope of supply (ref. [34]) in order to verify barrier fluid systems response and control and protection logics.

7.9.3.1 This emergency stop shall be performed in the in maximum speed and maximum differential pressure possible considering control and protection philosophy and the Dynamic Simulations results. This point shall be approved by Petrobras.

7.9.4 The Protection and Control Systems, including Load Sharing, shall be used during these evaluations and their performance shall be evaluated.

7.9.5 Pressure, liquid viscosity and temperature conditions for the EFAT tests shall be defined by agreement between SUPPLIER and PETROBRAS during DETAIL DESIGN STAGE. The worst-case MAY be considered by SUPPLIER in the bidding process.

7.9.6 During the EFAT a PRESSURE EQUALIZATION TEST shall be done. This test shall be proposed by the SUPPLIER and approved by PETROBAS in order to verify if the barrier fluid system is able to equalize the maximum pressure difference between barrier fluid and process as designed.

## 7.10 BFHPU System Tests

7.10.1 BFHPU System Tests conditions for the EFAT tests shall be defined by agreement between SUPPLIER and PETROBRAS during DETAIL DESIGN STAGE. The worst-case MAY be considered by SUPPLIER in the bidding process.

## 7.11 Control HPU System Tests

7.11.1 Control HPU System Tests conditions for the EFAT tests shall be defined by agreement between SUPPLIER and PETROBRAS during DETAIL DESIGN STAGE. The worst-case MAY be considered by SUPPLIER in the bidding process.

## 7.12 Control and Protection Systems Tests

7.12.1 Control and Protection Systems Tests conditions for the EFAT tests shall be defined by agreement between SUPPLIER and PETROBRAS during DETAIL DESIGN STAGE. The worst-case MAY be considered by SUPPLIER in the bidding process.

# 8 PUMP QUALIFICATION ASSURANCE – BIDDING PROCESS REQUIREMENTS

This section (8) relates to the minimum qualification of the BSRWI that shall have been performed before the bidding process.

8.1 SUPPLIER/BIDDER shall have a Subsea Pump of at least 1,5MW shaft power completely qualified for use in subsea boosting systems for ultra-deep-water applications (higher than 1,000-meter water depth) and pressure class 10kpsi as a minimum.

8.2 TRL 4, as per [8], shall be completely achieved before SUPPLIER/BIDDER proposal submission, i.e., a 1,5MW shaft power pump prototype shall have been designed, manufactured, fully tested and its designed performance features successfully validated with multiphase fluid (GVF >60%) prior to proposal submission.

8.2.1 TRC C for equipment and procedures, as per [7], shall be granted before SUPPLIER/BIDDER proposal submission, i.e., the same drawings, pre-qualified materials, components and sub-SUPPLIER chain, validated manufacturing procedures and process shall be used with only minor changes to fit integration in SUBSEA RAW WATER INJECTION SYSTEM.

8.3 SUPPLIER/BIDDER shall provide the Qualification Assurance Report for a Subsea Multiphase Pump of at least 1,5 MW, as per [8], with description and evidence of TRL 4, as per [8], and TRC C, as per [7], achievement throughout the Subsea 1,5MW Pump qualification process as part of SUBSEA RAW WATER INJECTION SYSTEM proposal.

8.4 Subsea Pump of at least 1,5 MW Qualification Assurance Report shall report, as a minimum, the following:

8.4.1 Detailed description of the tested equipment and its components including, but not limited to, pump shaft, impellers, bearings, seals, sensors and monitoring system.

8.4.2 Pump general arrangement.

8.4.3 Pump Datasheet as per [11].

8.4.4 Pump qualification test program goals, requirements and acceptance criteria summary including the complete list of test procedures and test report documents with document number, title, revision and emission date.

8.4.5 Description of test facilities used for pump qualification including test loop P&ID.

8.4.6 A summary of the qualification claims in relation to specified goals and requirements.

8.4.7 A summary of the evidence and related document number, title, revision and emission date, to support the qualification claims above.

8.4.7.1 As part of evidence, Subsea 1,5 MW Pump Qualification Report shall list the pump design reports that cover fluid mechanics, thermal, rotordynamic, shaft, and material compatibility analysis with document number, title, revision and emission date.

8.4.8 The manufacturer shall inform a list of changes that were made from the qualification pump to the final pump, including, but not limited to, items 8.3.8.1 to 8.3.8.3.

8.4.8.1 Improvements arising from pump manufacture and assembly procedures, tools and facilities.

8.4.8.2 Improvements arising from qualification testing and assessment.

8.4.8.3 Improvements in QC/QA procedures.

8.4.9 List of manufacturing, assembly, testing and QC/QA documents validated through pump qualification test program to achieve TRL 4, as per [8], and TRC C, as per [7] with document number, title, revision and emission date.

8.4.10 Potential pump and pump component´s weaknesses, and residual risks and uncertainty.

8.5 PETROBRAS, as its own discretion and during evaluation proposal phase prior to project award and also during all project stages, may ask for a dataroom to verify any document listed in the 1,5 MW Pump Qualification Assurance Report.

# 9 SUBSEA RAW WATER INJECTION PUMPING SYSTEM: STEADY-STATE AND DYNAMIC SIMULATIONS, RISK ASSESSMENT, DETAIL DESIGN, MATIC STAGE, INTEGRITY MANAGEMENT PROGRAM AND DECOMISSIONING

9.1 SUBSEA RAW WATER INJECTION SYSTEM Pumping System shall follow each requirement, stage, step and analysis in TS [35], including STEADY-STATE AND DYNAMIC SIMULATIONS, RISK ASSESSMENT, DETAIL DESIGN, MATIC STAGE, INTEGRITY MANAGEMENT PROGRAM AND DECOMISSINING.

9.1.1 For each meeting required for the items listed in 9.1 of this TS and in ref. [35] another meeting specific for the pumping system (Pump and Barrier Fluid) shall be scheduled with both PETROBRAS´ and Libra´s representatives using a web-based on-line meeting, conferencing and videoconferencing tool to deal with Pumping System specific topics. Petrobras may cancel or re-schedule any of these meetings.

9.2 Before the end of SUBSEA RAW WATER INJECTION SYSTEM DETAIL DESIGN STAGE, a Lateral Analysis Report in accordance with clause I.1 from [11] shall be provided for PETROBRAS approval.

9.2.1 The lateral Analysis Report shall provide the information identified as required for independent audit of the results.

9.2.2 The natural frequencies of the pump support structure must be calculated and presented in the report. A 20% separation margin shall be maintained between any structural natural frequency and the operating speed range, as suggested by item 9.3.5 from [11].

9.2.3 Besides the parameters defined in clause I.1.2 from [11], all rotordynamic analyses must also consider the variation of the following parameters in a sensitivity analysis:

9.2.3.1 Fluid composition, considering extreme values of viscosity.

9.2.3.2 Bearing load variation, considering that, for a vertical pump, the bearing load can greatly vary with changes in pressure and eccentricity between components.

9.2.3.3 Pump differential pressure variation, which translate in variation of seals dynamic coefficients. A dry pump case (barrier fluid only) analysis shall also be included in the analysis.

9.2.4 The analyses' acceptance criteria shall be applied to the most critical conditions identified within the operational range.

9.2.5 A damped unbalance response analysis in accordance with clauses I.1.4 and I.1.5 from [11] must be presented and the acceptance criteria shall apply regardless of the results from the separation margin and damping factor results.

9.3 Before the end of SUBSEA RAW WATER INJECTION SYSTEM DETAIL DESIGN STAGE, a Torsional Analysis Report in accordance with the requirements of item 6.9.2 from [11] Part 1 shall be developed and provided for PETROBRAS.

9.3.1 A steady-state, damped-response analysis shall be made.

9.4 Before the end of SUBSEA RAW WATER INJECTION SYSTEM DETAIL DESIGN STAGE, SUPPLIER shall yield a fluid flowing study on the SRWI SYSTEM (evaluating pressure drop and erosional velocity in the piping and valves of the SFB and pump module), using the base cases according [40] as input data.

9.5 During DETAIL DESIGN STAGE and during Manufacturing or Assembly in MATIC STAGE, CONTRACTOR shall submit to PETROBRAS each test operational procedure for comments. PETROBRAS and CONTRACTOR shall agree mutually the final version of these documents.

9.6 During MATIC STAGE, after the assembly of the sensors, for each motor-pump unit, the SUPPLIER shall verify the calibration of the sensors in order to comply with the requirements of ref. [18]. The SUPPLIER shall submit the calibration procedures for PETROBRAS approval.