Attributes of Production Chemicals in Subsea Production Systems

API TECHNICAL REPORT 17TR6
FIRST EDITION, MARCH 2012

AMERICAN PETROLEUM INSTITUTE

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Upstream Segment

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Foreword

This document was generated, by means of the BASICS Joint Industry Project (JIP) in response to the continuing problem of blockages occurring in control and chemical injection fluid conduits incorporated in subsea production systems (SPSs). The JIP committee comprised a representative cross section of experienced industry personnel from engineering, manufacturing and operational organizations.

Shall: As used in a standard, “shall” denotes a minimum requirement in order to conform to the specification.

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required in order to conform to the specification.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

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Introduction

Production chemicals delivered to a subsea production system (SPS) via a chemical injection system can be complex formulations that have a wide range of chemical and physical properties. In service, the production chemicals can come into contact with other fluids, metallic and polymeric materials, and a range of physical conditions in respect of temperature and pressure. Inadequate specification can therefore result in failure to deliver a production chemical to the required production system location.

The intent of the BASICS JIP is to produce a Specification (Spec) standard for global industry use to address this problem. This document has been developed with the objective of minimizing the risk of a production chemical not being delivered at the required volumetric rate, due to inadequate specification of the production chemical delivery system, or formation of restrictions or blockages in that system.

To do this, the document specifies parameters that address manufacture, storage and transportation of the production chemical, as well as its deployment using the SPS chemical injection system. The document provides for two approaches, requiring that parameters be either:

1) measured and reconciled with SPS design and operation; or

2) meet or exceed acceptance criteria specified, either in this document or by manufacturers of production chemicals or equipment used to deliver production chemicals.

Attention is drawn to the fact that in addition to the assessment and testing specified in this document, project specific assessments and tests may be required, and these should be agreed between the purchaser and the production chemical supplier or equipment manufacturer, as appropriate.

This document takes into account, many aspects of conventional SPS design and operation and also some common aspects of SPS failure that can impact on the application of a production chemical in an SPS. It should be noted however that any SPS can have specific features that in the event of failure may result in a blockage or restriction. Such system specific features and failures are not addressed by this document.

This document is intended to be applicable to all subsea developments, irrespective of whether the development is in shallow or deep water. However, it should be recognized that the significance of a blockage or restriction can be significantly different for a deepwater development relative to a shallow water development. Consequently, more rigorous application of the verification program could be appropriate for a deepwater development.

Attributes of Production Chemicals in Subsea Production Systems

1 Scope

This document identifies and specifies the essential attributes of production chemicals intended to be introduced to subsea oil and gas production systems.

The document is intended for use by chemical suppliers to facilitate the provision of chemicals compatible with existing and intended subsea production systems (SPS) although it is envisaged that use of the document for specification purposes by the operators of such processes, will assist in ensuring the completeness of requests to supply.

The application of the document requires acceptance of the principle that it is the supplier's responsibility to ensure that the chemicals supplied are fit for purpose and safe to use, although it is acknowledged that this responsibility can only be fulfilled if specification of requirements is complete. To this end the document identifies essential information that only SPS designers and operators can provide but without knowledge of which, suppliers should not supply. In the requirements of this document, responsibility for obtaining these items of critical information is placed upon the supplier, in the expectation that designers and operators will respond with their ready provision.

The functional performance of production chemicals is outside the scope of this document.

The assessments and tests specified in this document are not intended to qualify materials for use in an SPS in respect of pressure containment, mechanical load, cyclic mechanical load, or other design parameters.

The chemical-chemical compatibility of production chemicals at their respective application concentrations is also outside the scope of this document as is the effect of any incompatibility on their respective functional performance.

Finally, this document does not consider the health, safety, or environmental (HS&E) implications of deploying a production chemical in an SPS.

NOTE Attention is drawn to the fact that the tests specified in this document can generate data and information about the effect of a chemical/material incompatibility on the integrity of a material used in a SPS, that could necessitate additional testing, outside the scope of this document. Such additional testing should however be undertaken in order to ensure that all possible mechanisms that could threaten the integrity of a production, transportation, or chemical injection system are fully evaluated.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Specification 17D/ISO 13628-4, *Subsea Wellhead and Christmas Tree Equipment*

ASTM D471 [1], *Standard Test Method for Rubber PropertyEffect of Liquids*

ASTM D543, *Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents*

ASTM D638, *Standard Test Method for Tensile Properties of Plastics*

ASTM D664, *Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration*

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[1] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

ASTM D1141, *Standard Practice for the Preparation of Substitute Ocean Water*

ASTM D1298, *Standard Test Method for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method*

ASTM D4289, *Standard Test Method for Elastomer Compatibility of Lubricating Greases and Fluids*

ASTM G1, *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*

ASTM G31, *Standard Practice for Laboratory Immersion Corrosion Testing of Metals*

ASTM G46, *Standard Guide for Examination and Evaluation of Pitting Corrosion*

ISO 3771 [2], *Petroleum products—Determination of base number—Perchloric acid potentiometric titration method*

ISO 6073, *Petroleum products—Prediction of the bulk moduli of petroleum fluids used in hydraulic fluid power systems*

ISO 10523, *Water quality—Determination of pH*

ISO 13628-5, *Petroleum and natural gas industries—Design and operation of subsea production systems—Part 5: Subsea umbilicals*

IP 160 [3], Crude petroleum and liquid petroleum products - Laboratory determination of density - Hydrometer method

SAE AS4059 (2005) [4], *Aerospace fluid power—Cleanliness classification for hydraulic fluids*

3 Terms, Definitions, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1.1
attribute
Feature of a subsea production system that is fixed and inherent to the existence of the SPS.

NOTE Examples of SPS attributes are a material of construction or the volume of a vessel.

3.1.2
bacteriostat
Biological or chemical agent that prevents bacterial reproduction without killing or otherwise harming the bacteria.

3.1.3
barrier
Element forming part of a pressure-containing envelope which is designed to prevent unintentional flow of produced/injected fluids, particularly to the external environment.

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[2] International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.

[3] Energy Institute, 61 New Cavendish Street, London W1G 7AR, UK. www.energyinst.org

[4] Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, Pennsylvania 15096-0001, www.sae.org.

3.1.4
barrier arrangement

Provision of physical separation between two fluids during fluid change out in a fluid circuit, using a barrier element, e.g. a gel.

3.1.5
barrier fluid (spacer)

Fluid introduced to the SPS as an intermediary to provide physical separation between an existing fluid and the fluid intended to replace it during the change-out process.

3.1.6
biofilm

Viscous or gelatinous coating deposited on SPS components as a result of microbiological growth.

3.1.7
bunkering

Transfer of production chemical from transport container to host facility storage facility.

3.1.8
chemical reaction

Change of the chemical state of a substance, which may involve a change of oxidation state or molecular structure.

3.1.9
chemical injection system

Facilities that inject a production chemical into produced or injected fluids.

3.1.10
completion fluid

Fluid in the “A” annulus of a well between the production tubing and well casing.

NOTE 1 The fluid may have been in the well when the well completion (tubulars, screens, packer, etc.) were run into the well, or was circulated into the well after the well completion was run.

NOTE 2 Completion fluid can also be known as a “workover fluid”.

3.1.11
dead spot

Localized region in a fluid circuit whereby fluid in a flowing circuit is stationary or flows at a much lower velocity than the bulk fluid, e.g. step change in bore diameter.

3.1.12
delivery fluid

Fluid that is in the fluid conduits at the time of delivery of the SPS equipment.

NOTE This fluid may be the service fluid, or where not the service fluid, will be changed out with the service fluid following installation of the equipment.

3.1.13
fluid conduit

Steel tube or thermoplastic hose used in an umbilical, jumper bundle/assembly, rigid pipe-work, etc., for the transmission of fluids used in, or produced by a SPS.

3.1.14
fluid change-out

Replacement of a SPS service fluid by another fluid.

3.1.15
fluid stability
Condition of a fluid in which it is not liable to undergo chemical decomposition i.e. in which the characteristics of the fluid (chemical, physical, micro-biological) remain unchanged over time, after a disturbance, or having been subject to environmental exposure (UV, elevated temperature, etc.).

3.1.16
host facility
Offshore platform, floating facility or onshore facility to which the SPS is tied back.

3.1.17
hydrate
Compound in which water molecules form a solid ice like structure with methane, i.e. Type I or Type II methane hydrate.

3.1.18
hydraulic analysis
Detailed examination of SPS performance on the basis of calculating the variation of pressure in the chemical injection system as a function of production chemical injection rate, relative to system design pressure, in order to assess whether system performance in the various modes of operation is safe and operationally acceptable.

3.1.19
hydrocarbons
Produced hydrocarbons, which may be gas, condensate, oil and combinations of all three.

3.1.20
mapping
Process of making diagrammatic representations of aspects/issues relating to the design, manufacture, load-out and installation of the components that comprise the SPS, e.g. materials of construction, damage/potential damage locations.

3.1.21
operational envelope
Set of parameters that define the intended operational range of a SPS.

3.1.22
parameter
Feature of a subsea production system that is variable, measurable or quantifiable and fundamental to the nature and operation of the system.

NOTE Examples of SPS parameters are temperature; pressure; dose rate of a production chemical or oil production rate.

3.1.23
production chemical
Chemical, or mixture of chemicals, that are applied to produced or injected fluids in order to enable the production or injection process to take place, e.g. prevention of corrosion that could be caused by the produced or injected fluids; prevention of hydrate formation; prevention of mineral scale or wax deposition; H2S scavenging; demulsification; friction reduction.

NOTE A production chemical may also be referred to as “process chemical” or “chemical”.

3.1.24
produced fluid
The expected output of the SPS.

NOTE This is a collective term that includes oil, condensate, water, and gas.

3.1.25
shelf life
The time period in which a fluid remains stable and useable when stored in accordance with the manufacturer's storage and handling procedure.

3.1.26
solvent
Chemical that can dissolve or disperse another chemical so that the resulting liquid is either a solution or suspension of the other chemical.

NOTE The scientific definition is, "A liquid that dissolves a solid, liquid, or gaseous solute, resulting in a solution."

3.1.27
uptime requirement
Unit of time during which production chemicals are required to be injected.

3.1.28
yellow metal
Metal or metal alloy containing copper.

3.2 Abbreviated Terms

For the purposes of this document, the following abbreviated terms apply.

AS	Aerospace
CI	corrosion inhibitor or chemical injection
CITHP	closed in tubing head pressure
CRA	corrosion resistant alloy
FEED	front end engineering design
HPHT	high pressure high temperature, e.g. >10,000 psi and 150 °C
HP	high pressure, e.g. >10,000 psi
HS&E	Health, Safety, and Environment
HT	high temperature, e.g. >150 °C
IBC	intermediate bulk container
IMS	industrial methylated spirit
IRCD	injection rate control device
ISO	International Organization for Standardization
LDHI	low dosage hydrate inhibitor, e.g. kinetic hydrate inhibitor or anti-agglomerant hydrate inhibitor
MAWP	maximum allowable working pressure
NRV	non-return valve
OIW	oil-in-water
SAE	Society of Automotive Engineers

SI	scale inhibitor
SDU	subsea distribution unit
SPS	subsea production system
TAN	total acid number
TBN	total base number
UV	ultraviolet

4 Overview

Injection of a production chemical into produced fluids at a subsea location can be impeded by many incidents, events or combinations of these. Such causes can be related to SPS and chemical injection system design, production chemical specification, system commissioning, system maintenance, chemical change-out operation, fluid ingress, material degradation, etc. The consequences of being unable to inject production chemicals at the required rate and location can have significant economic impact. When restrictions or blockages occur, remediation may not be practicable or possible, therefore a significant cost may be incurred for replacement facilities. Alternatively, if remediation of restrictions or blockages is achievable, significant cost may still be involved due to the complexity of intervention where vessel mobilization is required.

Chemical vendors supply a wide range of production chemicals that may be applied in subsea systems. Production chemicals are often complex formulations that can change due to safety, performance, economic and environmental, requirements. They can be water based, hydrocarbon based, or an intermediate formulation and in addition, specific project functional requirements can necessitate formulation of new and unique products.

The production chemical requirement of a subsea development is dictated by the type of produced fluids. The produced fluids can consist of varying combinations of different types of oil, condensate, gas, and water ranging from condensed water that does not contain salts to formation water that contains salts close to salt saturation limits. Typical production chemicals include the following:

- scale inhibitors;
- corrosion inhibitors;
- methanol (hydrate inhibitor);
- ethylene glycol/monoethylene glycol/MEG (hydrate inhibitor);
- industrial methylated spirits/ethanol (hydrate inhibitor);
- wax inhibitors/pour point depressants;
- low dosage hydrate inhibitors (LDHIs);
- asphaltene inhibitors and dispersants;
- flow improvers;
- biocides;
- H_2S scavengers;
- demulsifiers;
- combined products, i.e. products that have dual function.

As a consequence of this background, it is necessary that project planning for SPS recognizes the wide range of criteria that should be considered when verifying a production chemical for deployment in a SPS and make provision for the time required for rigorous verification.

It is recommended that only production chemicals that have been verified to this specification and which fully meet the specified acceptance criteria, be deployed in an SPS. In addition, fluids used for installation, commissioning and production chemical change-out operations should be subject to verification as specified in this document.

It is also recommended that the responsibility of organizations associated, or directly involved, in data generation or verification processes, required by this document and their liability in the event of default, be specifically confirmed.

5 SPS Production Chemicals—Application Data

5.1 Supplier Responsibility

Before committing to supply a production chemical, the supplier shall be in possession of the values of the parameters that define the operational envelope within which that production chemical will be required to function. This shall include the parameters listed in Table 1, as a minimum.

NOTE This identifies the nature of the required application data, which should be part of the basis of system design and will include data required for specifying calculations, interpretation of reference data (e.g. materials compatibility data) and specifying laboratory test conditions.

Table 1—Parameters of the SPS Operational Envelope

SPS Parameters	Comments
Maximum and minimum application rates (volumetric rate) *	Required for verification that the chemical injection system can deliver the production chemical at the required volumetric rate, and estimation of the production chemical residence time.
Continuous or intermittent operation	Used to define duration of temperature stability tests.
Uptime requirement	Fraction or percentage of time when production chemical shall be injected.
Flow regime: laminar or turbulent flow	The majority of applications involve laminar flow, which will result in settling of solids that may cause blockage or restriction.
Temperature and pressure	The temperature and pressure data incorporating the known ranges and combinations for different locations in the production system, e.g. host, subsea, wellhead, bottom hole, as well as steady state versus transient operation.
Injection system design features	Any features that may be used to define required assessments or laboratory tests, for example: — common injection port used for more than one production chemical, which necessitates compatibility testing of the undiluted “as supplied” production chemicals; — component with a specified solids tolerance specification that requires testing of the production chemical compliance; — components for which a failure in service would result in mixing of a potentially incompatible production chemicals.
SPS chemical injection system materials map (materials wetted by production chemical)	Required for definition of chemical-material compatibility evaluation and testing.

* Determined by functional testing of the production chemical, which is outside the scope of this document.

5.2 Parameter Verification

The range of attributes addressed in this document relate to the installation, commissioning and operation of the SPS and is divided into those for which measurement shall be taken and reconciled against the SPS operational envelope and those for which acceptance criteria can be provided.

The attributes and related parameters addressed in clause 6 constitute the minimum requirement and shall be verified for every instance of production chemical supply.

Annex A sets out requirements relating to other attributes that may be relevant to some SPSs. For SPSs and associated production chemicals to which such attributes apply, the requirements of this annex shall be met.

6 SPS Production Chemicals—Common Parameters

6.1 General Application

The verification data provided in relation to a production chemical submitted for introduction to an SPS, shall include the parameters identified in 6.2 through 6.13, as a minimum.

6.2 Viscosity

6.2.1 Requirement

Viscosity measurements at a range of temperature/pressure combinations corresponding to host facility, subsea and well conditions, shall be taken to determine whether a production chemical can be injected at the required volumetric rate. The SPS operational envelope shall define the range of conditions selected for measurement of viscosity.

NOTE 1 Viscosity data are essential to determine whether or not a production chemical injection system can deliver at the required volumetric rate, or whether a production chemical has a viscosity that will permit its use in an existing injection system. The viscosity of a production chemical will vary as a function of temperature and pressure.

NOTE 2 The viscosity of hydrocarbon based production chemicals tends to exhibit the greatest pressure dependence. However, water/glycol based production chemicals can also exhibit a significant dependence. In addition, some production chemicals exhibit non-Newtonian behavior where viscosity varies as a function of shear rate.

6.2.2 Procedure

6.2.2.1 Measurement

Viscosity measurements shall be made using a method of the chemical providers own choosing, in accordance with a published standard. Reporting of the results of viscosity measurement shall always include identification of the method employed and corresponding standard. Should the SPS Operator not be satisfied with the results reported, the viscosity of the chemical shall be checked using one of the following methods:

- capillary viscometer;
- flow cup;
- rotational viscometer;
- rolling ball viscometer; and
- drawing ball viscometer.

6.2.2.2 Measurement at Elevated Temperature

Related viscosity measurement at elevated pressure shall be made using a method that is based on the principles of an atmospheric pressure measurement standard. Reporting of the results of viscosity measurement shall always include identification of the method employed and corresponding standard that is the basis of the method.

NOTE 1 OECD Guideline for testing of chemicals 114 "Viscosity of liquids" provides extensive details of available standards.

NOTE 2 Elevated pressures: Standards specifically for elevated pressure are not published. However, general specifications presented in standards can be applicable and should be considered when making measurements.

NOTE 3 It is recommended that at least two determinations should be made at each set of conditions.

6.2.3 Interpretation of Results

The measured viscosities shall be reconciled with the requirements of the SPS operational envelope to demonstrate that any specific production chemical can be injected at the required volumetric rate(s).

6.3 Density

6.3.1 Requirement

Density data are essential to the undertaking of an accurate hydraulic analysis of the production chemical injection system. Density measurement at a range of temperature/pressure combinations corresponding to the SPS operational envelope, shall be taken to determine whether a production chemical can be injected at the required volumetric rate.

6.3.2 Procedure

Density measurements shall be made using a method specified in a published standard and reference to the standard method used shall always be included in a report of results.

Where other specific standards are not selected for use and reference, either IP160 or ASTM D1298 shall be used as the default standard for the measurement of production chemical density.

6.3.3 Interpretation of Results

The measured densities shall be reconciled with the SPS operational envelope to demonstrate that any specific production chemical can be injected at the required volumetric rate(s).

6.4 Solvent Type

6.4.1 Requirement

Classification of solvent type shall be used as the basis for selection of compatible candidate flushing fluids and the assessment of the implications of mixing with the solvents used for installation, commissioning and flushing fluids, e.g. assessment of the likelihood of emulsion formation. For the purposes of this document, solvent type shall be classified as follows.

— **Water based:** Base solvent is fully miscible in water.

— **Hydrocarbon based (fully miscible):** Base solvent is fully miscible in hydrocarbon liquids such as diesel or kerosene.

- **Hydrocarbon based (partially miscible):** Base solvent is fully miscible with a limited number of hydrocarbon liquids such as diesel or kerosene.
- **Intermediate:** Base solvent fully or partial miscibility in both water and hydrocarbon liquids such as diesel or kerosene.

NOTE The above classification does not consider the potential for precipitation or separation of components that are part of the production chemical formulation. The potential precipitation or separation should be assessed using the procedures presented in 6.8 and 6.9.

6.4.2 Procedure

6.4.2.1 Determination of pH for Water Based Production Chemicals

The pH of a production chemical can be used to indicate possible chemical-chemical and chemical-material compatibility issues. Where determination of pH is required, the following method shall be used.

6.4.2.1.1 Equipment

Use a pH Meter, with glass electrode, having a measuring range from 0 to 14 pH units, graduated in 0.05 pH units.

6.4.2.1.2 Method

The principles and methods specified in ISO 10523, *Water quality—Determination of pH*, shall be used. Where required, dilution of the production chemical to increase the speed of the pH electrode response, is permissible.

NOTE "Definitions of pH scales, standard reference values, measurement of pH, and related terminology," *Pure Appl. Chem.* (1985), 57, pp 531–542., should also be consulted.

6.4.2.2 Hydrocarbon Based Production Chemicals

Where production chemicals are formulated with solvents other than water, pH measurement are unlikely to be appropriate. Hydrocarbon based production chemicals can contain acidic or basic components. TAN and TBN represent the amount of acidic and basic components, respectively.

6.4.2.2.1 TAN

TAN shall be determined in accordance with ASTM D664, *Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration*.

6.4.2.2.2 TBN

TBN shall be determined in accordance with ISO 3771, *Determination of base number—Perchloric acid potentiometric titration method*.

6.4.3 Interpretation of Results

6.4.3.1 The pH at temperatures corresponding to those experienced in the SPS operational envelope shall be recorded and reported.

The pH data can be used to assess possible chemical-material compatibility issues and chemical-chemical compatibility issues, e.g. reactive hazard potential, emulsion stability, etc.

6.4.3.2 The TAN or TBN data derived from production chemicals shall be compared to data derived from the SPS operational envelope to assess possible chemical-material and/or chemical-chemical compatibility issues, e.g. reactive hazard potential, emulsion stability.

6.5 Particulates

6.5.1 Requirement

Production chemicals will contain variable amounts of particulates which will have the potential to cause blockages and/or restrictions in a SPS. Particulate content shall be determined and reported in respect of any production chemical supplied.

6.5.2 Procedure

Determination of particulate content of a production chemical shall be undertaken in accordance with SAE AS4059.

Where a production chemical has been manufactured to have a specific particulate content, the same procedure shall be used to verify the manufacturing process.

6.5.3 Interpretation of Results

The contamination code derived from SAE AS4059 for the production chemical shall be reconciled with the SPS operational envelope to ensure the production chemical will not cause a blockage or restriction.

6.6 Temperature Stability

6.6.1 Requirements

The stability of a production chemical shall be evaluated over the range of temperatures corresponding to those experienced in the SPS operational envelope.

The evaluated temperatures shall correspond to those associated with:

- transportation;
- day/night fluctuation;
- geographical location;
- storage;
- subsea application;
- downhole well injection.

The evaluated temperatures shall also take inot accoun the likely duration of exposure to particular temperature associated with normal operational conditions and SPS shutdown.

6.6.2 Procedures

6.6.2.1 General

6.6.2.1.1 The Test Vessel

The preferred test vessell shall adhere to the following.

a) Be of glass and fitted with a screw cap but in all cases shall be confirmed as being inert in respect of the production chemical.

NOTE Where the production chemical is shown to react in contact with glass, a vessel of alternative material inert in the presence of the production chemical is used.

b) Be sized such that when the sample volume of production chemical is inserted, the headspace in the test vessel shall be not less than 10 % and not more than 20 % of the test vessel volume, so as to minimize the effect of solvent evaporation.

c) In all cases, allow visual observation of the production chemical during the test.

d) Have its internal surface swabbed with a cotton bud to test for evidence of residue or deposit on completion of the test.

NOTE The swabbing shall be performed immediately when the bottle or vessel is emptied so that any residue does not significantly change temperature.

6.6.2.1.2 The Test Sample

Test sample volumes shall be not less than 100 ml and not greater than 300 ml.

6.6.2.1.3 Evaluation Conditions

The following conditions apply when performing sample evaluations.

a) A strong light shall be used when visually examining a test sample.

b) The test sample shall be compared to a reference sample of the production chemical.

c) Visual observations shall be made and recorded at the start and at the end of the test, and where practical periodically during the test.

NOTE It is recommended that photographs be used to record the condition of the test sample.

d) Samples of separated phases, deposits, and precipitates shall be separated and stored for further characterization.

NOTE Such samples may be used to ascertain suitable solvents that might be used to clean an SPS chemical injection system, or to characterize the cause of any production chemical instability.

6.6.2.2 Low and Moderate Temperature Tests

The following apply when performing low and moderate temperature tests.

a) Bottles should be used for low to moderate temperature tests. The suitability of the bottle for the test temperature should be verified with the manufacturer.

b) Test durations of not less than three months shall be applied to allow for the potentially slow chemical reaction kinetics at low temperature.

   NOTE It is recommended that test periods of even longer duration be applied, if the specific operating conditions of a SPS suggest this to be appropriate.

c) The low end test temperature of the range tested shall be not less than 3 °C lower than the lowest recorded or estimated, operating temperature of the SPS.

6.6.2.3 High Temperature Tests

The high end test temperature of the range tested shall be not less than 10 °C higher than the highest recorded or estimated, operating temperature of the SPS.

6.6.2.4 Temperature Change Tests

The effect on production chemicals of temperature changes within the SPS shall be evaluated, e.g. any increase from ambient seabed temperature to the temperature at the injection port in a wellhead tree, immediately prior to injection into the produced fluids.

The evaluation shall simulate the rate of temperature increase specific to the application.

6.6.2.5 Temperature Cycling Tests

Production chemicals can experience temperature variations during transportation and storage that may go beyond the range of the temperature variation experienced in the SPS. Where records or estimation show this to be the case, tests simulating the transportation and storage conditions shall be performed. The temperature variations applied shall include frequent cycling where transport and storage conditions are shown to include such conditions.

6.6.3 Interpretation of Results

A production chemical shall be considered stable when:

- precipitates/sludge are not formed;
- bulk phase separation does not occur;
- solidification does not occur;
- adherent deposits or residues are not formed on the test vessel;
- viscosity and density is unchanged relative to a reference sample;
- pH or TAN/TBN are unchanged relative to a reference sample;

— any suspended or dispersed material present in the production chemical before testing, e.g. micro-emulsion, shall not have separated or settled.

If a particulate specification has been defined, the procedure presented in 6.6 shall be applied to determine if the test sample complies with the specification.

Test results consistent with the above acceptance criteria shall be recorded.

NOTE A production chemical found to be unstable under transportation conditions can be considered acceptable for subsea application provided that the instability is reversible and does not occur at the application conditions.

6.7 Hydrate Stability

6.7.1 Requirements

Production chemicals shall not form a hydrate under the conditions to be experienced in the operational envelope of the SPS. This shall be assessed/tested by one of the procedures provided in 6.7.2 of which that in 6.7.2.3 is preferred.

NOTE 1 The significance of 6.8.1 is that production chemicals containing water can potentially form methane hydrates when mixed with produced hydrocarbons, e.g. due to an NRV not being "gas tight" and allowing gas to enter the chemical injection system. The resulting hydrate can block and/or restrict chemical injection systems

NOTE 2 Attention is drawn to the fact that NRVs in subsea chemical injection systems are by design not "gas tight".

NOTE 3 Hydrates can potentially form in subsea chemical injection systems due to backflow of water saturated hydrocarbon gas, e.g. due to passing an NRV. This mechanism of hydrate formation is not dependent on the formulation of the production chemical. However, the production chemical may prevent hydrate formation due to being formulated with a thermodynamic hydrate inhibitor, assuming effective mixing can be achieved.

NOTE 4 It should be noted that hydrocarbon-based production chemical formulations are unlikely to contain components that act as thermodynamic hydrate inhibitors.

6.7.2 Procedure

6.7.2.1 General

Derivation of a hydrate dissociation curve for assessment of the potential for hydrate formation in a chemical injection system shall be based on the full range of operating conditions to be experienced in the intended SPS (see Note 1, Note 2, and Note 3).

A detailed composition of the produced hydrocarbon, i.e. N_2, CO_2, CH_4, C_2H_6, C_3H_8, n-C_4H_{10}, i-C_4H_{10}, etc., shall also be determined.

NOTE 1 The potential for a production chemical to form a hydrate is primarily a function of temperature and pressure, and the composition of the different fluids in the system, e.g. production chemical and hydrocarbon composition.

NOTE 2 The minimum temperature is usually the ambient seabed temperature. However, the potential for Joule-Thomson cooling below ambient seabed temperature during operation should be assessed.

NOTE 3 The maximum system pressure is normally the CITHP. Alternatively, the subsea chemical injection system relief pressure, or MAWP, may be appropriate for definition of the maximum system operating pressure.

6.7.2.2 Theoretical Evaluation

6.7.2.2.1 Introduction

Simulation tools that allow calculation of hydrate dissociation curves are commercially available. In addition, simple spreadsheet models can be developed based on published methods and correlations. A simulation tool can be used in various ways to assess the potential for hydrate formation, which may involve making assumptions due to limitations of the tool or absence of data describing the system of interest.

Several methods for assessing hydrate formation potential using simulation tools are presented below but, in all cases, the user shall determine the accuracy of the chosen tool.

6.7.2.2.2 Simple Theoretical Assessment

This procedure, which requires the following assumptions:

— the components of the production chemical formulation do not act as either a hydrate inhibitor or hydrate promoter;

— the simulation tool can explicitly simulate the hydrate inhibitor to be added to the production chemical formulation.

shall be undertaken as follows.

a) Establish:

    1) pressure and temperature range of the chemical injection system;

    2) composition of the produced hydrocarbon;

    3) water content of the production chemical to be applied;

    4) hydrate inhibitor to be added to production chemical formulation, e.g. ethylene glycol, 2-butoxyethanol, salt, etc.

b) Calculate the following using a simulation tool:

    1) the hydrate dissociation curve for a pure water; and

    2) the hydrate dissociation curve for pure water plus increasing fractions of the hydrate inhibitor.

c) Determine the required fraction of hydrate inhibitor to be added to the production chemical formulation to prevent hydrate formation over the full operating range of temperature and pressure.

6.7.2.2.3 Tuned Assessment Based on Freezing Point Suppression

This method which relies on the assumption that the profile of the hydrate dissociation curve over the operating pressure and temperature range is independent of the type of hydrate inhibitor added to the formulation, shall be undertaken by measuring the freezing point of a production chemical formulation in accordance with the following procedure:

a) Establish:

    1) pressure and temperature range of the chemical injection system;

  2) composition of the produced hydrocarbon;

  3) freezing point of the production chemical.

  NOTE Increasing the proportion of hydrate inhibitor, e.g. ethylene glycol, 2-butoxyethanol, salt, etc., will decrease the solution freezing point.

b) Define a composition that matches the measured freezing point, using a simulation tool, ensuring a match with the freezing point suppression due to the hydrate inhibitor.

NOTE For example, the composition used in the simulation can be a simple water and ethylene glycol, or water and sodium chloride composition. The hydrate inhibitor that will be used in the actual production chemical formulation does not have to be used in the simulation composition. The important requirement is to match the freezing point suppression due to the hydrate inhibitor.

c) Use the simulation tool to calculate hydrate dissociation curve for the composition in the presence of the produced hydrocarbon. Based on the hydrate dissociation curve, establish if the production chemical formulation will form a hydrate at any of the combinations of temperature and pressure of the SPS operating envelope.

d) Repeat the procedure for different production chemical formulations to establish a formulation that does not form a hydrate at the operating conditions.

NOTE 1 Typically, suppression of freezing point by 10 °C will result in hydrate dissociation suppression of ~6.25 °C.

NOTE 2 Freezing point suppression can be dependent on the system pressure due to the dissolution of gas into liquid phase. This can be significant for HP systems.

NOTE 3 See bibliography for further methods.

6.7.2.2.4 Tuned Assessment Based on Single Point Hydrate Dissociation Measurement

This method which relies on the assumption that the profile of the hydrate dissociation curve over the operating pressure and temperature range is independent of the type of hydrate inhibitor added to the formulation, shall be undertaken by measuring a hydrate dissociation point (temperature and pressure) for the production chemical in accordance with the following procedure.

a) Establish:

  1) Pressure and temperature range of the chemical injection system.

  2) Composition of the produced hydrocarbon.

  3) Hydrate dissociation point of the production chemical—see 6.8.3 for description of laboratory method. The measurement should be made at temperature and pressure conditions in the region of the SPS operating envelope.

b) Use a simulation tool to define a composition that matches the measured hydrate dissociation point, e.g. the composition used in the simulation can be a simple water and ethylene glycol, or water and sodium chloride composition. The hydrate inhibitor that will be used in the actual production chemical formulation does not have to be used in the simulation composition. The important requirement is to match the hydrate dissociation point.

c) Use the simulation tool to calculate hydrate dissociation curve for the composition in the presence of the produced hydrocarbon. Based on the hydrate dissociation curve, establish if the production chemical formulation will form a hydrate at the full operating range of temperature and pressure of the SPS.

d) Repeat the procedure for different production chemical formulations to establish a formulation that does not form a hydrate at the operating conditions.

6.7.2.3 Hydrate Dissociation Curve Measurement

6.7.2.3.1 Introduction

Standards for measurement of hydrate dissociation points are not published. However, many laboratory service providers have methods for measurement of hydrate dissociation points. Numerous authors have published details and discussion of the methods.

Methods include the classical thermodynamic method, where hydrate dissociation temperatures *vs.* pressure curves are determined using pressure *vs.* temperature measurements in a constant volume cell (PVT). Calorimetric methods such as high pressure differential scanning calorimetry (DSC) can also be used.

6.7.2.3.2 Requirements

General requirements for measurement of hydrate dissociation points shall be as follows.

a) The capability of a laboratory service provider to accurately measure hydrate dissociation points shall be verified, e.g. measurement of a known hydrate dissociation point.

b) Hydrate dissociation points shall be measured, as opposed to hydrate formation points. This allows for the sometimes significant degree of subcooling below the hydrate thermodynamic equilibrium that can occur before a hydrate forms.

c) Replicate measurements shall be made for each dissociation point. At least three dissociation points over the SPS operating range shall be measured.

6.7.3 Interpretation of Results

The production chemical shall not form a hydrate for any of the pressure and temperature combinations that define the operating envelope of the chemical injection system.

6.8 Chemical-Chemical Compatibility

6.8.1 Requirements

Qualification of a production chemical shall be based on determination of its potential for mixing in the conditions to be experienced in the SPS and on evaluation of the compatibility of the mixture components.

NOTE 1 During operation of an SPS, a production chemical in the “as supplied” form can mix with other production chemicals, flushing, installation and commissioning fluids, produced hydrocarbons and sea water. The mixing may be due to system design, a specific operation, human error, or failure of a component of the SPS. Mixing may result in phase separation and formation of solids, deposits and gels that may restrict or block the chemical injection system.

NOTE 2 A compatibility assessment can use existing data, or can be based on a specific laboratory evaluation. Many production chemicals are complex proprietary formulations that can only be reliably assessed for compatibility by laboratory testing. However, published data can be used to screen production chemical formulations for possible compatibility issues.

6.8.2 Procedure

6.8.2.1 Compatibility Assessment Using Existing Data

A compatibility assessment shall take into account the following aspects of a chemical injection system, with respect to the potential for mixing and definition of appropriate assessment and laboratory testing:

— design and normal operation, e.g. injection ports where “as supplied” chemical can mix with other chemicals and produced fluids;

- installation and commissioning, e.g. mixing with installation fluids;
- flushing or change-out operations, e.g. mixing flushing fluid with incumbent fluid due to fluid flow characteristics;
- SPS dead legs and tees;
- injection system component failure, e.g. NRV failure that results in backflow of produced fluids, or other production chemicals into the chemical injection system;
- maintenance, e.g. mixing of "as supplied" chemical with seawater due to hose disconnection during diver operations;

A compatibility matrix across the entire array of chemicals to be used in the intended SPS shall be prepared (see Figure 1). The content of the matrix can be based on existing data, or specific laboratory test data. Example of the range of chemicals that may need to be considered is given in Table 2.

NOTE It is recommended that an assessment of the potential for mixing and consequences include consultation with the responsible subsea engineer, maintenance engineer, equipment vendor, and operations team.

It shall be recognized that static compatibility tests will not definitively determine if a blockage will occur due to incompatibility. The characteristics of an incompatibility shall be used to assess the likelihood of blockage based on the specific characteristics of the production chemical injection system, e.g. connector type restrictions, potential for settling, and accumulation.

	Chemical 1	**Chemical 2**	**Chemical 3**	**Chemical 4**	**Chemical 5**
Chemical 1					
Chemical 2	🟧 Stable tight emulsion at 50:50 mixture				
Chemical 3	🟥 Fine solid: exceeds AS4059 class 8 B to F	🟩			
Chemical 4	🟨 Thin oil layer formed	🟩	🟦 Polymerises (ref 1)		
Chemical 5	🟦 Gel on side of test bottle	🟨 2 immiscible layers	🟥 Large amount of coarse solid	🟩	

Key:

🟩	Compatible	🟨	Phase separation	🟥	Solid precipitation	🟦	Gel formation	🟧	Emulsion formation

Figure 1—Example of a Compatibility Matrix

Table 2—Example Range of Chemicals Included in a SPS Chemical Compatibility Matrix

Chemicals Possibly Present in a Subsea Production System (SPS)
Chemical injection system delivery, commissioning, and pre-fill fluids
Scale inhibitor
Corrosion inhibitor
Methanol—hydrate control, pressure testing and pressure equalization
Glycol—hydrate control, pressure testing and pressure equalization
Wax inhibitor
Pour point depressant
Low dosage hydrate inhibitors (LDHI)
Asphaltene inhibitor/dispersant
Flow improver
Biocide
H_2S scavenger
Oxygen scavenger
Demulsifier
Hydraulic fluid: water based
Hydraulic fluid: oil based
Spacers or barrier fluids: Fluids to maintain separation of production chemicals during change out operations

6.8.2.2 Chemical-Chemical Compatibility Testing

6.8.2.2.1 Introduction

The testing procedures described is this section are based on the premise that the respective chemicals are likely to mix in a wide range of proportions, e.g. trace or gross contamination of a production chemical may occur.

The procedures described are applicable for numerous operations and scenarios associated with an SPS.

6.8.2.2.2 Laboratory Static Testing Procedure

The volumetric mixing ratios of chemicals specified in Table 3 are recommended as a minimum requirement. The same ratios can be used on a mass basis and the procedure below modified, if required.

In the following test, it is assumed that the effect of pressure is not significant but the test temperature to be evaluated shall be defined by the range of conditions in the intended SPS. Tests at numerous temperatures can therefore be required.

The following procedure shall be followed for each mixing ratio.

a) Select sample bottles of not less than 100 ml and not more than 300 ml capacity. If a pressure cell has to be used, select a vessel that allows visual examination.

b) Measure the required volume of each production chemical and record the ambient laboratory temperature.

Table 3—Compatibility Test Mixing Ratios (vol/vol)

Test	Production chemical	Chemical *
1	0	1.00
2	0.01	0.99
3	0.05	0.95
4	0.20	0.80
5	0.50	0.50
6	0.80	0.20
7	0.95	0.05
8	0.99	0.01
9	1.00	0.00

* Chemical: Production chemical, hydraulic fluid, etc.

c) Place in a refrigerator or bath until the required test temperature is attained.

d) Mix the respective production chemicals and agitate by hand shaking. To ensure complete mixing, an ultrasonic bath or laboratory bottle shaker may be required for production chemicals that have moderate to high viscosity, or are only partially miscible.

NOTE The mixing characteristics of the SPS should be considered and replicated if considered potentially significant. The procedure in 6.9.3.2 should be considered.

e) Visually observe the mixture for evidence of the following:

- solids precipitation;
- phase separation;
- gel formation;
- emulsion formation;
- immiscibility.

f) Carefully examine the air/liquid interface, and sides and bottom of the bottle, in addition to the bulk liquid. Gentle agitation should be used to suspend solids or separated phase to ease observation.

g) Record and photograph the observations and maintain the test temperature.

h) Repeat the visual examination with gentle agitation after 1 hour, 4 hours, 24 hours, 1 week, and 1 month. Photograph at each examination time.

i) Extend the duration of the compatibility test, if the residence time of the chemical in the subsea chemical injection system is likely to exceed one month.

j) On completion of the test, characterize the test sample as follows.

- Check for evidence of gels, or separated phases that have adhered to the bottle using a cotton bud that is rubbed against the glass.

NOTE For production chemicals that have a high viscosity or strong tendency to wet the bottle surface, adequate time should be allowed for the production chemical to drain.

- Record the properties of solids, gels, or emulsions, e.g. sticky or friable solids; soft or strong gel; etc.
- Samples that exhibited incompatibility should be retained to allow further characterization.

k) If an emulsion is formed, consider measuring the emulsion viscosity to establish if the emulsion could be displaced from an umbilical.

l) If necessary, the particulate content should be characterized. Compliance with any relevant particulate tolerance specification pertaining to components of the subsea chemical injection system should be evaluated. The method presented in 6.5 shall be used.

NOTE Chemical-chemical compatibility references are provided in the bibliography at the end of this document. The reliability of the data in references presented in this document has not been verified.

6.8.2.2.3 Flow Loop Testing

Static compatibility tests will not definitively determine if a blockage will occur due to incompatibility. Circumstances, or perceived risk, may justify a dynamic test that simulates flow and operating conditions of the SPS, e.g. where an incumbent production chemical has a known incompatibility with available flushing fluids or a high degree of assurance is required for a high value asset. Dynamic tests could be small-scale laboratory tests or large scale tests using sections and components of an SPS.

The following procedure shall be undertaken for each dynamic flow loop test.

a) Replicate the anticipated mixing characteristics of the system, which will be dependent on flow type (i.e. laminar versus turbulent), temperature, hydraulic restrictions such as poppet valves, etc.

b) Replicate the operating fluid velocities in the test.

c) Use flow loop dimensions consistent with the SPS, e.g. conduit internal diameter.

NOTE Consider using SPS components that potentially have the greatest sensitivity to production chemical incompatibility, e.g. control valves with small orifice sizes.

d) Use differential pressure measurement to assess fluid compatibility in the test system.

e) Use inert dyes, e.g. food coloring, to track fluid breakthrough.

f) Sample fluids and record observations. Photograph fluid samples and/or video the test.

g) On completion of the test, flush the flow loop at maximum possible velocity to remove any precipitates, gels, or solids that may have accumulated in the flow loop.

6.8.2.3 Chemical-Produced Fluid Compatibility

6.8.2.3.1 Introduction

Production chemicals in the “as supplied” form may mix with produced fluids, e.g. hydrocarbons or produced water. The mixing of a production chemical and produced fluid can result in the formation of solids, deposits, etc., that may cause a blockage due to incompatibility.

NOTE The mixing may be due to the design and operation of an injection system, e.g. an injection open port may experience backflow of produced fluids, due to fluid compression or component failure.

6.8.2.3.2 Requirement

The compatibility of all production chemicals present in the SPS, irrespective of solvent type, shall be assessed.

6.8.2.3.3 Procedure

Select samples of all types of produced fluids in the SPS, e.g. oil, condensate, gas, produced water. This shall include determination of the fluid properties, e.g. oil API gravity , gas CO_2 content, produced water divalent cation concentration, etc.

Samples of produced fluids used in testing shall be representative of their condition at the respective point in the SPS, e.g. oil or water samples should not contain production chemicals that are applied downstream of the point of mixing that is being evaluated.

Samples of produced fluids shall be preserved in the 'as taken' state, e.g. oil should not be allowed to oxidize during storage.

6.8.2.3.4 Laboratory Testing

The procedure presented in 6.8.2.3.3 shall be used with the mixing ratios presented in Table 4.

Table 4—Compatibility Test Mixing Ratios (vol/vol)

Test	Production chemical	Produced fluid
1	0	1.00
2	0.01	0.99
3	0.05	0.95
4	0.20	0.80
5	0.50	0.50

NOTE In some circumstances, the compatibility of a production chemical and a produced gas may need to be evaluated, e.g. where a produced gas contains high concentrations of acid gases such as CO_2 and H_2S, and the production chemical formulation contains basic components that could chemically react.

The following procedure shall be undertaken for testing the compatibility of a production chemical and a gas.

a) Use an inert vessel that allows visual observation during the test.

b) Use the effective partial pressure of specific gas components, e.g. pCO_2 or pH_2S, to reduce the test pressure and hence the requirement for high pressure laboratory equipment.

c) Consider the effect of evaporation of the production chemical solvent when specifying the test. This may require bubbling of the gas through the production chemical.

6.8.2.4 Chemical-Seawater Compatibility

6.8.2.4.1 Introduction

Subsea operations may require maintenance and fault finding interventions that require disconnection and reconnection of SPS conduits containing production chemicals. As consequence, the production chemical will experience some degree of sea water contamination. The degree of contamination is dependent on the type of connection, and a wide range of mixing ratios of production chemical and sea water can occur.

It shall be assumed that a production chemical deployed in an SPS will at sometime be contaminated with seawater unless specific design and operational procedures have been adopted to prevent contamination. Consequently, the compatibility of the production chemicals and seawater shall be evaluated.

6.8.2.4.2 Requirement

The compatibility of all production chemicals, irrespective of solvent type, shall be assessed.

6.8.2.4.3 Procedure

The procedure presented in 6.8.2.3 with the mixing ratios presented in Table 5 shall be used.

Table 5—Compatibility Test Mixing Ratios (vol/vol)

Test	Production chemical	Sea Water
1	0	1.00
2	0.05	0.95
3	0.20	0.80
4	0.50	0.50
5	0.80	0.20
6	0.95	0.05
7	1.00	0.00

Testing the compatibility of a production chemical and seawater shall be undertaken in accordance with ASTM D1141.

6.8.3 Interpretation of Results

6.8.3.1 Compatibility Assessment (Using Existing Data)

Extensive chemical-chemical compatibility data are published in the open literature. The data can be used to assess potential incompatibility of production chemicals, or components of a production chemical. The data may be entered into the required compatibility matrix, but should be verified as being accurate.

NOTE As a consequence of the complex formulation of some production chemicals, reliance on reference data for components of the production chemical formulation is not recommended.

6.8.3.2 Compatibility Testing

An assessment of the potential for blockage and/or restriction shall be based on the specific aspects of each SPS design and shall include the definition of acceptance criteria for each specific SPS.

NOTE The ideal situation is that a production chemical will be compatible under all circumstances, including failure of SPS components. If a production chemical is demonstrated to be incompatible, an alternative should be sourced.

However, as a consequence of functional requirements that dictate formulation of production chemicals, a production chemical that is compatible under all circumstances may not be available.

This situation will require management of the incompatibility and shall include the following:

- Assessment of the probability of mixing incompatible fluids and the safety, economic and environmental consequences.

- Definition of verified remedial operations for a known incompatibility, e.g. solvent flushing, or component replacement.
- Operational procedures that eliminate or reduce the potential for mixing of incompatible fluids, e.g. flushing of chemical injection lines before breaking connections.
- SPS designs that eliminate or reduce the potential for mixing of incompatible fluids.

NOTE 2 Production chemicals that are deployed in an SPS should be compatible to a degree where the properties of the mixture will not cause a blockage or restriction. The potential for blockage and/or restriction is system-specific. As a consequence, some degree of incompatibility may be tolerable. Incompatibility that may be acceptable for some SPS includes:

- light friable non-adherent precipitates that do not settle;
- immiscible liquids that do not form an emulsion;
- liquid with slightly elevated viscosity.

Incompatibility that is unlikely to be acceptable under any circumstances includes:

- solidification of the whole test sample;
- high viscosity emulsion;
- thixotropic liquid (shear thickening liquid);
- “sticky” adherent deposits that cannot be mobilized;
- precipitates that aggregate and form a concretion;
- solids, gels, or deposits from an incompatibility that cannot be removed, e.g. by solvent flushing.

6.9 Umbilical Displacement

6.9.1 Introduction

During installation and operation of subsea chemical injection systems, fluids will need to be displaced, e.g. displacement of the fluid used to install an umbilical to the production chemical that will be injected using the chemical injection facility.

The displacement operation may require use of a spacer fluid that prevents mixing of incompatible fluids. It is recommended that as part of the qualification of a production chemical, a flushing fluid that is compatible with the production chemical and is likely to be compatible with the majority of other fluids that may be used be identified (see Annex B). The fluid can be used as the spacer fluid for displacement operations.

6.9.2 Requirements

Before performing a displacement operation, it shall be verified that the fluids that will mix during the operation are compatible. The compatibility of the fluids including spacer fluids, shall be verified using the procedure in 6.8.2.3.

NOTE The procedure considers a wide range of mixing ratios due to fluid flow characteristics in chemical injection systems, which is predominantly laminar.

The potential for mixing of incompatible fluids due to SPS design shall be assessed, e.g. the potential for manifold “dead legs” that are not displaced to result in mixing of incompatible fluids.

6.9.3 Laboratory Static Testing Procedure

6.9.3.1 Introduction

Table 6, and the procedure that follows it, provide for the assessment of the compatibility of mixtures of a production chemical (X), another production chemical (Y), and a spacer fluid (Z). The production chemical (X) is to be replaced in the chemical injection system by production chemical (Y).

Table 6—Compatibility Test Mixing Ratios (vol/vol)

Test	Z	X	Y
1	1	1	0
2	1	1	0.2
3	1	1	1
4	1	1	4
5	1.6	0.4	0
6	1.6	0.4	0.2
7	1.6	0.4	1
8	1.6	0.4	4
9	1.8	0.2	0
10	1.8	0.2	0.2
11	1.8	0.2	1
12	1.8	0.2	4

The following procedure shall be followed for each mixing ratio.

a) Select sample bottles of not less than 100 ml and not more than 300 ml capacity. If a pressure cell has to be used, select a vessel that allows visual examination.

b) Measure the required volume of each chemical and record the ambient laboratory temperature.

c) Place in a refrigerator or bath until the required test temperature is attained.

d) First, mix appropriate volumes of X and Y, and gently agitate by hand shaking. Record ease of mixing.

e) When mixed, add required volume of Z, and gently agitate by hand shaking. Record ease of mixing.

f) Visually observe the mixture for evidence of the following:

— solids precipitation,

— phase separation,

— gel formation,

— emulsion formation,

— immiscibility.

g) Carefully examine the air/liquid interface, and sides and bottom of the bottle, in addition to the bulk liquid. Gentle agitation should be used to suspend solids or separated phase to ease observation.

h) Record and photograph the observations and maintain the test temperature.

i) Repeat the visual examination with gentle agitation after 30 minutes, 1 hour, 4 hours, and 24 hours, and 1 week. Photograph at each examination time.

6.9.3.2 Flow Loop Testing

The requirements and guidance presented in 6.8.2.2.3 shall be followed.

6.9.4 Interpretation of Results

6.9.4.1 On completion of the test, characterize the test sample as follows.

a) Check for evidence of gels or separated phases that have adhered to the bottle using a cotton bud that is rubbed against the glass.

  NOTE For production chemicals that have a high viscosity or strong tendency to wet the bottle surface, adequate time should be allowed for the production chemical to drain.

b) Record the properties of solids, gels, or emulsions, e.g. sticky or friable solids; soft or strong gel; etc.

c) Samples that exhibited incompatibility should be retained to allow further characterization.

6.9.4.2 If an emulsion is found to have formed, consider measuring the emulsion viscosity to establish if the emulsion could be displaced from an umbilical.

6.9.4.3 If necessary, the particulate content should be characterized. Compliance with any relevant particulate tolerance specification pertaining to components of the subsea chemical injection system shall be evaluated using the method presented in 6.5.

6.10 Supply and Installation Fluids

6.10.1 Introduction

Subsea equipment and umbilicals will contain fluids when supplied and installed. The fluids are predominantly inert fluids that are intended to allow safe transport and installation, and to ensure system integrity. The fluids will be displaced to the production chemical, or hydraulic fluid, before operation of the SPS.

NOTE Common supply and installation fluids include water/glycol mixtures, hydraulic oils, mineral oils, and hydrocarbon solvents.

6.10.2 Requirement

The compatibility of the supply and installation fluids shall be verified using the procedures presented in 6.8.2.2.

6.11 Chemical-Material Compatibility

6.11.1 Introduction

An SPS chemical injection system can contain many different materials that will come in contact with production chemicals. Also, the production chemicals will contact materials that are used in the construction of vessels, pumps, hoses, valves, connectors, and many other components used in manufacturing, transportation, transfer, and storage facilities. Contact with such material has the potential to cause instability in a production chemical that could subsequently cause a blockage or a restriction in a chemical injection system. In addition, an incompatibility may cause a loss of integrity of the chemical injection system.

6.11.2 Requirements

6.11.2.1 Responsibility for Obtaining the Relevant Specification

In line with 5.1, for every instance of new supply, production chemical suppliers shall be in possession of unequivocal definition of all SPS parameters relevant to the use of the production chemical(s) requested.

In repeat order situations, suppliers shall request confirmation that the previously supplied parameters are still current.

NOTE It is recommended that SPS designers/operators create a materials map identifying all the materials in a chemical injection system flow path that have potential to come into contact with a production chemical. The materials map should be made available to potential suppliers of production chemicals for use in definition of the required chemical-material compatibility testing or assessment. The materials map should:

- include material specifications and operating conditions, so that tests can be adequately defined, or to allow verification that existing data are relevant;
- consider possible variation of material properties within recognized specifications, giving sufficient detail to allow differentiation of grades of material within a specification.

6.11.2.2 Production Chemical Support

A production chemical supplied for use in an SPS shall be supported by the following.

- A chemical-material compatibility assessment based on existing data (see 6.11.2.3, 6.11.2.4, and 6.11.2.5)
- The results of testing the production chemical in relation to the specific application with specification of the tests used (see Annex C). When practical, chemical-material compatibility testing shall be undertaken using a sample of the actual material used in the chemical injection system construction.

6.11.2.3 Compatibility Assessment Pre-qualification

The majority of subsea chemical injection systems are constructed from a range of engineering materials commonly used for this purpose and because of this it is possible for a production chemical supplier to test a production chemical for chemical-material compatibility against a range of materials, without having knowledge of a specific application.

Such prequalification of production chemicals for subsea application can reduce the time required for deployment of a production chemical for a specific application.

In the event of prequalification being considered by a production chemical supplier, the list of materials presented in Table 7 references materials typically used in SPS and that therefore should be included in chemical-material prequalification testing.

6.11.2.4 Compatibility Assessment Using Existing Data

For most engineering materials, there are extensive data for chemical-material compatibility for commonly used chemicals, e.g. methanol. The data will vary with industry sector with respect to the associated conditions, e.g. temperature and pressure, but will consider typical operating conditions encountered in the oil and gas industry.

Table 7—Candidate Production Chemicals for Pre-qualification Testing

Metals	304 stainless steel
	316 stainless steel
	410 stainless steel
	17-4 PH stainless steel
	22Cr duplex stainless steel
	25Cr super duplex stainless steel
	Inconel 825
Elastomers	FKM (A type fluorocarbon or Viton Class A)
	Viton Class B
	HNBR (hydrogen nitrile rubber)
	NBR (nitrile rubber or Buna N)
	Neoprene
	EPDM (ethylene propylene rubber)
	PVC (polyvinyl chloride)
	Tungsten carbide with 10%Ni binder
	Silicon nitride
Thermoplastics	Nylon
	HDPE (high density polyethylene)
	PP (polypropylene)
	PVC (polyvinylchloride)
	Teflon (polytetrafluoroethylene)
	FRP (fiberglass reinforced plastic)
	Kevlar (Hydlar ZF)
	PTFE
	PEEK

These data can be exploited to eliminate chemical-material combinations that are likely to be incompatible, so avoiding unnecessary testing. Also, the data can be used to assess chemical-material combinations that could be further evaluated in testing.

In some cases, the existing data may be adequate to confirm chemical-material compatibility, e.g. methanol compatibility with common engineering metals and alloys.

The SPS vendor, SPS component manufacturer and the material manufacturer will have chemical-material compatibility data. These data will be predominantly for common chemicals such as methanol, or chemicals that might be a major component of production chemical formulation, e.g. ethylene glycol.

In addition, production chemical vendors may have chemical-material compatibility data for specific products in relation to common materials, e.g. 316L stainless steel, duplex stainless steel, nitrile rubber, nylon, etc. Table 8 provides examples of compatibility data sources.

Use of existing chemical-material compatibility data shall include confirmation as to:

Table 8—Examples of Chemical-Material Compatibility Data Sources

Data Sources
Material Safety Data Sheets (MSDS) from chemical vendors
Chemical vendor product datasheets
SPS component manufacturers
Material manufacturers
Public access databases
Industry bodies for specific materials
Materials selection consultancies

— **The reliability of the data**—The compatibility of complex production chemical formulations which may be determined by a minor component of the production chemical and not the major components of the production chemical that may have extensive chemical-material compatibility data associated with them.

NOTE It is recommended that complex production chemical formulations are always tested against all flow path materials.

6.11.2.5 Compatibility Assessment Based on Operating Experience

The operational experience of an existing chemical injection system can be used as a qualification basis for a chemical-material combination. If this form of assessment and qualification is used, the following shall be taken into account:

a) the similarities of the existing system relative to the system being assessed, e.g. operating temperature and pressure, type of production chemical, etc.;

b) the duration of operation of the existing system relative to the required lifetime of the system being assessed;

c) confirmation that the existing system is fully operational;

d) confirmation of the integrity of the existing system.

NOTE Where practicable, components of the existing system should be recovered and examined to verify the compatibility of chemical-material combinations.

6.12 Manufacturing Tolerance—Quality Control Specifications

It is essential that production chemicals intended for use in SPS be manufactured to a specification that provides acceptance ranges for selected parameters and properties. Suppliers of such chemicals shall ensure that supplied chemicals have been manufactured using a quality control process that identifies and provides traceability for compliant and non-compliant product batches.

NOTE The variation of the product batches should be evaluated in respect of the properties, parameters and assessments detailed in the previous sections of this document. Periodic testing of product batches selected at random should be considered.

Annex A
(normative)

Additional Attributes

A.1 General

A subsea production system (SPS) may have design and/or operational features that are outside the range considered common to all SPS and which are therefore not considered in the body of this document.

An SPS operational envelope can require that certain additional attributes need to be evaluated.

Sections A.2 through A.8 address some attributes that, although not common, could be characteristic of particular SPSs and that will therefore require evaluation as attributes in that connection. These clauses include requirements that shall be fulfilled where the attribute is thus identified.

This list is not considered to be exhaustive, and users of this document are strongly recommended to assess any SPS under consideration for additional, unusual design and operational features. The attributes thus identified may require the development and specification of non-standard assessment procedures, e.g. laboratory test procedures. It is recommended that in all cases, appropriate expertise be consulted in respect of these attributes and their related parameters.

A.2 Permeation

Some components of an SPS may be susceptible to permeation of some or all components of a production chemical, e.g. some thermoplastics may be susceptible to permeation by methanol.

The consequences of mixing of the production chemical components with other fluids should be considered in the context of formation of solids or phases that may cause blockage or restrictions in other conduits.

If chemical-chemical compatibility testing is considered necessary, the procedure presented in 6.8 shall be used.

NOTE The potential and extent of permeation can be assessed using the procedure described in C.4.6.4.

A.3 Non-wetted Component Compatibility

Permeation of some or all components of a production chemical through containment materials in an SPS, or failure of an SPS component to contain a production chemical, may result in a production chemical contacting SPS materials that are not wetted during normal operation. Incompatibility may subsequently cause system failure.

If chemical-material compatibility testing is considered necessary, the procedure presented in 6.11 shall be used.

A.4 Bulk Modulus

Production chemicals can exhibit differing degrees of compressibility, which can be expressed as a bulk modulus. In general, hydrocarbon based production chemicals have the greatest degree of compressibility.

The compressibility of a production chemical is unlikely to cause a blockage. However, for some production chemical injection systems that are part of long distance subsea tiebacks, or injection systems operating over a wide pressure range, compression of a production chemical may significantly interrupt injection of the production chemical.

An SPS should be evaluated for the possible effect of compressibility, and if considered to be a potential issue, the bulk modulus of the production chemical(s) measured to quantify the effect.

Measurement of bulk modulus shall be in accordance with ISO 6073 (all parts).

A.5 Electromagnetic Fields

Production chemicals delivered using an umbilical can be exposed to variable electromagnetic fields associated with the electrical power transmission system in the umbilical. The strength of an electric field will increase as voltage increases and the strength of a magnetic field increases as electric current flow increases.

A possible consequence of exposure to an electromagnetic field could be inductive heating. Separation of a production chemical that is a dispersion is also possible.

Based on experience, interaction of electromagnetic fields with production chemicals has not been attributed to operational problems. However, technology development may give rise to situations that merit evaluation, e.g. increased power transmission beyond conventional design. Also, deployment of complex production chemical formulations, e.g. dispersions or micro-emulsions, that may be affected by an electromagnetic field. For these situations, it is recommended that the potential for an adverse interaction be evaluated.

Evaluation of the potential for interaction, and definition of test procedures and electrical environment, should consider consultation of expertise, e.g. an electrical engineer, in respect of electromagnetic testing of electrical components.

The acceptance criteria presented in 6.6 shall be applied.

A.6 Vibration

It is known that vibration can affect fluids, e.g. by dispersing solids, causing cavitation, or initiating chemical reactions. Vibration is more likely to be significant for complex production chemical formulations, e.g. dispersions, emulsions, or products that have a limited stability range.

Variable frequency vibration can occur in an SPS. Relevant expertise should be consulted in defining the characteristics, e.g. frequency and amplitude, of any vibration in the SPS, and if considered unconventional, representative testing should be conducted.

The acceptance criteria presented in 6.6 shall be applied.

A.7 Light

Some circumstances may arise where production chemicals can be exposed to direct sunlight, e.g. where chemicals are supplied and/or stored in transparent plastic IBCs. The light intensity will vary with geographical location.

The production chemical vendor should be consulted about the potential for degradation due to light, and if considered to be a potential risk, a test procedure established.

Standard methods for the measuring the degree of light degradation of production chemicals are not available. It is recommended that a laboratory test procedure be developed that replicates the operating conditions, based on a site survey of the light intensity during transportation and/or storage for the specific application.

The acceptance criteria presented in 6.6 shall be applied.

NOTE If a production chemical is demonstrated to be light sensitive, use of opaque IBCs should be considered.

A.8 Microbiological Stability

Bacteria have the potential to breakdown components used to formulate production chemicals. The metabolic processes of the bacteria that breakdown the chemicals can result in the formation of solids or biofilms. The solids and biofilms have the potential to cause restrictions and blockages in a chemical injection system.

Production chemicals tend to be formulated with components that are readily biodegradable due to environmental legislation that discourages the use of chemicals that do not biodegrade and would accumulate in the environment.

The degradation of a production chemical by bacteria will be dependent on many different parameters. These include:

- temperature: A range of 10 °C to 60 °C would typically be optimal for bacterial degradation of a production chemical;
- chemical concentration: High concentration solutions can prevent bacterial degradation and dilute chemicals are more likely to be prone to bacterial degradation;
- type of chemical: Some types of chemical are easily metabolized by bacteria;
- availability and replenishment of nutrients required by bacteria;
- type of bacteria: There are many different types of bacteria that can metabolize different chemicals and have different optimal conditions for proliferation;
- degree of contamination of the production chemical with bacteria;
- presence of chemicals that act as biocides or biostats.

Consequently, it is not possible to reliably predict if bacterial degradation will occur.

Based on experience, most production chemicals are not prone to bacterial degradation in the as supplied form. However, the potential does exist and should be taken into account for unusual production chemical formulations, or for formulations containing components that are known to be readily degraded by bacteria. The production chemical vendor and a microbiologist should be consulted.

Contamination of production chemical may create conditions that promote bacterial degradation, e.g. seawater contamination due to breaking of a subsea connection that could introduce a wide variety of different bacteria and additional nutrients.

Testing of the potential for bacterial degradation of a production chemical shall use representative conditions. A microbiologist should be consulted in respect of defining a representative and informative test, e.g. a culture test using representative consortia of bacteria.

Annex B
(informative)

Recommended Spacer Fluids

It is recommended that the following fluids should be considered for use as spacer fluids:

- 2-Butoxyethanol (ethylene glycol) monobutyl ether (EGMBE);
- ethylene glycol (MEG);
- EGMBE/water mixture or MEG/water mixture (the mixture should contain sufficient MEG or EGMBE to prevent hydrate formation when in contact methane at likely operating conditions);
- naphtha based hydrocarbon solvents;
- base oil hydrocarbon solvents.

The spacer may act as a physical barrier that separates incompatible fluids, or as solvent that allows mixing of incompatible fluids.

When selected, the compatibility of the spacer fluid shall be verified using the procedure presented in 6.9.3.

Annex C
(normative)

Chemical-Material Compatibility Laboratory Testing

C.1 Introduction

There are numerous published standard methods for materials testing that can be used to evaluate the compatibility of chemical-material combinations. In addition to published standard methods, component manufacturers and system suppliers, and materials testing laboratories, have their own proprietary test methods. The manufacturer or supplier may require tests to be performed as the basis of a guarantee of component or system performance.

NOTE API 17D provides a standardized set of procedures to verify additive compatibility with materials associated with subsea completion hardware.

It is essential that test methods conditions be representative of the conditions likely to be experienced in the intended SPS. Decision as to the rigor and complexity of the testing should be take into account the consequences of incompatibility of a chemical-material combination within the SPS.

The duration of rigorous chemical-material compatibility testing can be several months. Consequently, testing should be initiated to allow adequate time to confirm acceptability of chemical-material combinations. Alternatively, accelerated aging tests based on the Arrhenius principle, which relates rate of reaction to temperature, can be used to reduce the duration of testing.

For each material type, this Annex presents a simple description of the principles of testing a chemical-material combination; an outline description of a reference test method; acceptance criteria; and refers to appropriate supporting references. Attention is drawn to the fact that the different materials used in a chemical injection system may require fundamentally different test methods, e.g. permeation of a chemical through a material is only relevant to thermoplastics and elastomers, and not in respect of metals. Consultation of materials engineering and selection expertise may be required to identify all necessary testing.

It is recommended that several test specimens, whether metal, elastomer, or thermoplastic, be tested for different durations, e.g. one day, one week, and three months. The objective is to establish the characteristics of the incompatibility, e.g. a continuous degradation of the material during the whole duration of the test, an instantaneous material degradation, an initial material degradation followed by no further change of material or fluid properties, etc.

C.2 Test Conditions

C.2.1 The range of operating temperatures and pressures of the chemical injection system shall be determined for each material and used to define test conditions.

C.2.2 The effect of transient operation and heat transfer from the surrounding environment shall be taken into account when defining a test. In addition, inaccuracies in estimated conditions shall be allowed for by either marginally increasing or decreasing the parameter test value as appropriate, e.g. +10 °C relative to maximum operating temperature.

C.2.3 Definition of the test duration shall consider the design life of the SPS; the mechanisms that may be the cause of incompatibility and the associated induction times; and the reliability of extrapolating from data derived from a short duration test. A three-month minimum test duration is recommended for typical applications.

C.3 Test Fluids

C.3.1 Introduction

Chemical-material compatibility tests can be used to evaluate the compatibility of a production chemical and a material.

For some SPS, it may appropriate to consider a situation where the chemical injection system has become contaminated, so that a test consists of a production chemical, a material and a contaminant. The potential for contaminants to enter a production chemical injection system has been addressed in 6.8.2.3, “Chemical-Produced Fluid Compatibility,” and 6.8.2.4, “Chemical-Sea Water Compatibility.”

It is essential that evaluation of the compatibility of a chemical-material-contaminant combination recognizes the potential for contamination to create a more aggressive environment in respect of the material relative to the production chemical alone, i.e. a contaminant and production chemical may act synergistically.

C.3.2 Chemical/Material/Contaminant Combination

Testing a chemical-material-contaminant combination shall differentiate between the chemical-contaminant compatibility addressed in 6.8.2.3, “Chemical-Produced Fluid Compatibility” and 6.8.2.4, “Chemical-Sea Water Compatibility.” Also, the results from tests including contaminants shall be compared to those of tests consisting of only a chemical-material combination.

C.3.3 Relative Proportions of Production Chemicals and Contaminants

Testing shall use representative relative proportions of production chemicals and contaminants.

NOTE For subsea operations may require maintenance and fault finding interventions that require disconnection and reconnection of SPS conduits containing production chemicals. As consequence, the production chemical will experience some degree of seawater contamination. The degree of contamination is dependent on the type of connection and a wide range of mixing ratios of production chemical and seawater can occur.

C.3.4 Immiscible Fluids

Tests relating to SPS situations involving immiscible fluids shall ensure that the material is exposed to both fluids.

NOTE In some situations a production chemical and contaminant will be immiscible. However, partitioning of chemical components of the production chemical or contaminant may occur. This may be significant in determining how aggressive an environment is with respect to a material.

C.3.5 Sea Water

Tests evaluating the effect of seawater contamination shall use either natural seawater, or artificial seawater according to the ASTM Standard D1141-98. Reporting on sea water contamination testing shall include identification of which method was adopted and in addition, the potential contribution of bacteria, such as sulphate reducing bacteria (SRB) and acid generating bacteria, to material degradation shall be taken into account. If found to be potentially significant, the presence of the relevant bacteria shall be included in the test fluid definition.

C.3.6 Selection of Produced Fluid Samples

Tests evaluating the effect of produced fluid contamination shall use one of:

- actual field fluids;

— an analogue produced fluid;

— an artificial fluid that closely represents the produced fluid.

And reporting of fluid testing shall include reference to which sample type was used.

C.4 Chemical Material Compatibility Test Methods

C.4.1 General

Claims of compatibility between supplied chemicals and a particular SPS shall be supported by satisfactory reports of testing undertaken in relation to actual SPS operating conditions. Chemical providers may use either the default methods provided in this Annex or select alternative equivalent tests. In all cases, the test method used shall be clearly identified in the outcome report used to support a claim of compatibility.

C.4.2 Accelerated Aging Tests

C.4.2.1 Test Type

Accelerated aging tests may be used to reduce the time to evaluate a chemical-material combination. The test may use:

a) a conventional real time test method, e.g. the chemical-material compatibility test methods described in C.4.3, C.4.4, C.4.5, and C.4.6;

b) an accelerated aging test based on the principles of Arrhenius reaction rate theory.

NOTE Arrhenius reaction rate theory, states “a rise in temperature of 10 °C will double the rate of a chemical reaction.”

C.4.2.2 Arrhenius Reaction Rate Theory

a) The principle can be used to define test durations in terms of an accelerated aging rate (AAR) as follows:

$$AAR = Q_{10}^{((T_s - T_t)/10)} \tag{C-1}$$

where

T_s is the service temperature;

T_t is the test temperature;

Q_{10} is the reaction rate.

b) The duration of an accelerated test can then be expressed as accelerated aging time duration ($AATD$) as follows:

$$AATD = \frac{D_s}{AAR} \tag{C-2}$$

where

D_s is the service duration.

Example calculation:

If the SPS system lifetime is 20 years, the operating temperature is 4 °C and the test temperature is chosen to be 55 °C, Q_{10} is 2.5; the *AATD* is determined as follows:

$$AAR = Q_{10}^{((55-4)/10)} = 89.1 \text{ days}$$

$$AATD = \frac{20 \times 365 \text{ days}}{AAR} = 82 \text{ days}$$

C.4.2.3 Conditions Governing the Use of Accelerated Aging Tests

The choice as to whether or not accelerated ageing tests shall be used shall take account of the following.

a) The Q_{10} value variation of different types of chemical reaction, e.g. inorganic chemical reactions tend to have a Q_{10} factor of approximately 2.

NOTE The Q_{10} for thermoplastics can be in the order of 3. It is important to select an appropriate factor for the chemical-material combination being evaluated and specifically the type of chemical reaction that may be the basis of an incompatibility. Ideally the Q_{10} for all chemical reactions should be established and lowest value used to define the test duration.

b) Multi-component materials and production chemicals may react at different rates, which correspond to different Q_{10} factors.

c) Reaction rates above 50 °C may not be linear.

d) At elevated temperature, the stability of production chemicals may become a significant factor, e.g. evaporation of solvent causing unrepresentative destabilization of a production chemical.

e) At elevated temperature, the type of chemical reaction may change relative to chemical reactions at the service temperature, or a mode of material failure may occur that also does not occur at the service temperature, e.g. exceeding the stress corrosion cracking (SCC) threshold of a metal.

   At elevated temperature, the properties of a material may change, e.g. a thermoplastic may exceed the glass transition temperature.

C.4.2.4 Real Time Test Method

The real time test method that is the basis of the accelerated aging test should be verified as appropriate for elevated temperatures.

C.4.3 Chemical-Material (Metals)—Default Compatibility Test Procedure

C.4.3.1 Principles

Testing shall be undertaken on the basis of chemical-material compatibility of metals based on immersion testing, as follows.

C.4.3.2 Test Specimen Preparation

a) Metal specimens shall be prepared in accordance with ASTM G1, *Standard Practice for Preparing, Cleaning and Evaluating Corrosion Test Specimens*.

b) Specimens should have a representative surface condition.

c) For some chemical injection systems, the interaction between different materials, or method of construction can be significant in determining the compatibility of chemical-material combinations.

NOTE A weld, a crevice formed by a connection, a tensile stress applied to a material by “make-up” of a connection, or galvanic couple between materials.

d) Specimens should be used that are representative of the actual system, if there is a perceived risk.

NOTE A ceramic washer can be used to create a crevice, or a C-ring can be used to simulate material under tensile stress.

NOTE Materials and corrosion expertise should be consulted when planning and defining these tests.

C.4.3.3 Procedure

a) The default procedure for a chemical-compatibility/material test shall incorporate the principles described in ASTM G31, *Laboratory Immersion Corrosion Testing of Metals,* and be undertaken as C.4.3.3 b) through C.4.3.3 j).

b) Weigh test specimen, to nearest 0.0001 g.

c) Place test specimen in a labeled bottle and fill the bottle with test fluid (see 6.12.5.2. “Test Fluids” for definition of test fluid) until the test specimen is completely immersed.

d) Seal the bottle and place in an environmental chamber that will maintain the required test temperature for the required duration.

e) Periodically remove bottles and visually examine the test specimen for evidence of change.

f) After the required test duration, remove a bottle from the environmental cabinet. Remove the test specimen and rinse with an appropriate solvent(s).

g) Report the appearance of the fluid and test specimen, e.g. discoloration, rust, sediment, pitting, cracking, crusting, etc.

h) Remove any corrosion product with steel wool and re-rinse. Use acetone as a final rinse and air-dry the test specimen for one hour.

i) Reweigh to nearest 0.0001 g and calculate the total metal loss and corrosion rate based on the area of the test specimen.

j) Perform macroscopic and microscopic examination of the test specimen.

k) Examine the fluid for evidence of precipitates, phase separation, change of properties, etc.

C.4.3.4 Testing Synthetic Fluids

Testing synthetic fluids and oils, the standard method ASTM D665 can be used. The method is based upon exposing carbon steel samples in an agitated mixture of oil and artificial seawater (60 °C for 24 hours). The acceptance criterion for this test is no visible rust. The ASTM D665 method can be modified for testing of other materials.

C.4.3.5 Test Specimen Examination

Examination of the test specimen shall use the principles described in ASTM G31, *Laboratory Immersion Corrosion Testing of Metals*, and ASTM G46, *Inspection and characterization of corrosion products and corrosion attacks*.

C.4.4 Chemical-Material (Metals) Acceptance Criteria

The acceptance criteria for chemical-material compatibility shall be as follows.

C.4.4.1 Fluid

Acceptance criteria as specified in 6.6.3.

C.4.4.2 Metal

a) A general corrosion rate consistent with the SPS lifetime.

b) Stable general corrosion rates that tend to decline over time.

c) No localized corrosion, i.e. crevice, pitting, or cracking.

d) A particulate corrosion product size and quantity consistent with the SPS specified solids tolerance limit based on the contamination code system specified in SAE AS4059.

C.4.5 Chemical-Material (Elastomers) Compatibility Test Procedure

C.4.5.1 General

The basis of the procedure for the assessment of chemical-material compatibility of elastomers based on immersion testing shall be as follows.

C.4.5.2 Test Specimen Preparation

a) Elastomer test specimens shall be prepared in accordance with the principles specified in ASTM D471, *Standard Test Method for Rubber Property—Effect of Liquids*, or ASTM D4289, *Standard Test Method for Elastomer Compatibility of Lubricating Greases and Fluids*.

b) Elastomer specimens shall have a deforming force applied, e.g. folded 180 degrees, to simulate the service conditions and the required material performance, i.e. an elastomer shall have the rubber-like property of substantially recovering its size and shape after removal of a deforming force.

C.4.5.3 Procedure

Procedures shall be in accordance with ASTM D471 or ASTM D4289. The default procedure for a chemical-compatibility material test shall be as follows.

a) Measure the required test specimen properties, e.g. dimensions, weight to the nearest 0.0001 g, Shore A or D hardness, etc.

b) Place test specimen in a labelled bottle and fill the bottle with test fluid (see 6.12.5.2, “Test Fluids,” for definition of test fluid) until the test specimen is completely immersed.

c) Seal the bottle and place in an environmental chamber that will maintain the required test temperature for the required duration.

d) Periodically remove bottles and visually examine the test specimens for evidence of change.

e) After the required test duration, remove a bottle from the environmental cabinet. Remove the test specimen and rinse with an appropriate solvent(s) for the elastomer and test fluid.

f) Report the appearance of the fluid and test specimen, e.g. discoloration, shape, swelling, surface appearance, cracking, crusting, etc.

g) Remove any deposits, rinse with acetone and air-dry the test specimen.

h) Perform macroscopic and microscopic examination of the test specimen.

i) Measure the test specimen properties that were measured at the start of the test, and establish changes, e.g. appearance, weight, volume change (swelling), hardness, tackiness, and elongation.

j) Examine the fluid for evidence of precipitates, phase separation, change of properties, etc.

C.4.5.4 Chemical-Material (Elastomers) Acceptance Criteria

C.4.5.4.1 The acceptance criteria for chemical-material compatibility shall be as follows.

— Fluid:

  1) Acceptance criteria as specified in 6.6.3.

— Elastomer:

  1) Dimension change shall not exceed ±10 % in any dimension.

  2) Weight change shall not exceed ±10 %.

  3) Tensile strength change shall not exceed ±10 %.

  4) Hardness change shall not exceed ±10 %.

  5) Volume change shall not exceed the range – 5 % to +10 %.

  6) The development in volume and hardness change with time shall show a clear tendency to stabilization.

  7) No cracking or crazing (visual examination).

  8) No tackiness.

C.4.6 Chemical-Material (Thermoplastics) Compatibility Test Procedure

C.4.6.1 General

The default procedure for the assessment of chemical-material compatibility of thermoplastics, based on immersion testing, shall be as follows.

NOTE This includes consideration of the pressure loading that a thermoplastic tube encounter in service.

C.4.6.2 Test Specimen

Thermoplastic test specimens shall be prepared in accordance with the principles specified in ASTM D543, *Standard Test Method for Evaluating the Resistance of Plastics to Chemical Reagents*, as a minimum.

NOTE A closer representation can be achieved through the use of test specimens prepared from thermoplastic tubes in the form of tubes in umbilicals and flexible connection jumpers, as described in IS0 13628-5, *Petroleum and natural gas industries—Design and operation of subsea production systems–Part 5: Subsea Umbilicals*, 7.9.7.12, “Fluid compatibility tests.”

C.4.6.3 Default Immersion Test Procedure

C.4.6.3.1 The immersion test shall be based on the procedure described in C.4.5.2 and the principles described in ASTM D543 and IS0 13628-5, section on “Immersion tests.” Example properties and standard for measurement that shall be evaluated are as follows:

- UTS: ASTM D638;
- Elongation: ASTM D638;
- Hardness Shore D.

C.4.6.3.2 An immersion test utilizing a tube test specimen shall use the principles and the specific details in respect of pressure cycling, and accelerated aging, as described in IS0 13628-5, section on “Fluid compatibility tests.”

C.4.6.3.3 The default procedure for a test, utilizing a tube test specimen shall be as follows.

a) Set the test temperature to an appropriate value using the principles described in C.4.5.2.

b) Pressure cycle from atmospheric pressure to the tube MAWP using a 5 minute period for pressure increase and decrease and a 1 hour hold time at MAWP.

c) The test duration should be 3 months.

d) Utilize the pass/criteria described in IS0 13628-5, section on “Fluid compatibility tests.”

C.4.6.4 Permeability Test Procedure

The default permeability test, utilizing a tube test specimen, shall use the principles described in IS0 13628-5, section on “Permeability Tests”.

C.4.6.5 Chemical-Material (Thermoplastics) Acceptance Criteria

The acceptance criteria for chemical-material compatibility shall be as follows.

- Fluid:
    1) Acceptance criteria as specified in 6.6.3.
- Thermoplastic:
    1) Dimension change shall not exceed ±5 % in any dimension.
    2) Weight change shall not exceed ±5 %.
    3) Tensile strength change shall not exceed ±5 %.
    4) Hardness change shall not exceed ±5 %.
    5) The development of tensile strength change with time shall show a clear tendency to stabilization.
    6) No failure of tube test specimens that have been tested by pressure cycling.

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