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PRODUCED WATER TREATMENT AND INJECTION FACILITIES

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DESIGN AND ENGINEERING PRACTICE

DEM1



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for the design of produced water treatment system (upstream surface facilities) for:

Produced water re-injection	Waterflood projects where produced water is used as the water source For both onshore and offshore application
Well disposal	Produced water well disposal in non-producing reservoir or aquifer Both onshore and offshore
Surface discharge to sea	Surface disposal to sea of produced water

The produced water treatment system boundary starts at the produced water outlet of the bulk separation equipment and stops at last treatment step in the produced water system, including associated water quality monitoring.

The scope of this DEP also covers:

- The impact of bulk separation of the reservoir fluids on the produced water treatment system
- Discharge to sea and produced water injection pumps design aspects.

The scope of this DEP does not cover well design.

This DEP relates to conventional produced water treatment, reservoir fluids from operations with use of conventional chemicals i.e., excludes EOR chemicals.

The scope of equipment covered includes produced water treatment facilities for:

- solids removal
- dispersed oil removal
- degassing
- dissolved hydrocarbon removal

The DEP scope excludes:

- Disposal of produced water inshore (rivers, reed beds and evaporation ponds)
- Subsea produced water treatment

This DEP consolidates the applicable content of the following documents, which are replaced in part by this DEP and other documents:

- EP 2007-5475, Waterflood Manual, Chapter 6: Surface Facilities
- Deoiling manual

For seawater based waterflood reference is made to DEP 39.01.40.30-Gen. For bulk separation of the well fluids reference is made to DEP 20.04.10.11-Gen.

The DEP addresses the selection of technology alternatives within the produced water system configuration. It also specifies the minimum technical requirements for the technology selected within the configuration. Detailed mechanical and process equipment design requirements to meet the functional requirements herein are beyond the scope of this DEP.

This DEP contains mandatory requirements to mitigate process safety risks in accordance with Design Engineering Manual (DEM) 1 – Application of Technical Standards.

This DEP is a revision of the same number dated February 2016; see (1.5) regarding the changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them. Any authorised access to DEPs does not for that reason constitute an authorisation to any documents, data or information to which the DEPs may refer.

This DEP is intended for use in facilities related to exploration and production facilities. This DEP may also be applied in other similar facilities.

When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The capitalised term **SHALL [PS]** indicates a process safety requirement.

The word **should** indicates a recommendation.

The word **may** indicates a permitted option.

1.3.2 Specific definitions

Term	Definition
Deployable technology	Engineering and operating experience exists in the Principal or a development release has been made (containing the operating envelope and associated application uncertainties/risks). Note that a technology could be deployable for a certain application but this does not automatically define this technology deployable for another application. The operating envelope as defined in the development release determines the extent of the deployable application
Produced hydrocarbon liquids	Hydrocarbon liquid phase in reservoir fluids, which can be classified as crude oil or condensate.
Produced water	All water streams separated in the processing plant.
Proven technology	Synonym for a deployable technology. All proven technologies have uncertainties in characteristic of the feed stream and their operating envelope.
Reservoir fluids	Fluids produced from a reservoir. For a hydrocarbon bearing reservoir the reservoir fluids consist of hydrocarbon liquids, formation water (including connate water) and gas.
Waterflood	Waterflood is a method of recovery in which water is injected into the reservoir to displace additional oil and/or to help maintain reservoir pressure.
Well disposal	Well disposal is a method in which produced water is injected into a non-producing reservoir or aquifer with the aim to dispose produced water

1.3.3 Abbreviations

Term	Definition
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
EOR	Enhanced Oil Recovery
IGF	Induced Gas Flotation
IOR	Improved Oil Recovery
LAT	Lowest Astronomical Tide
LP	Low Pressure
MPPE	Macro Porous Polymer Extraction
NPD	Naphthalene, Phenanthrene, Dibenzothiophene
NPSH	Net Positive Suction Head
OIW	Oil in Water
PAH	Polyaromatic Hydrocarbons
PW	Produced Water
PWRI	Produced Water Re-injection
RAM	Reliability, Availability and Maintenance
SRB	Sulphate Reducing Bacteria
VRU	Vapour Recovery Unit

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section or clause number is shown in brackets ().

Other documents referenced by this DEP are listed in (5).

1.5 SUMMARY OF MAIN CHANGES

This DEP is a revision of the DEP of the same number dated February 2016. The only changes are to DEP cross-references to reflect changes in the DEP library in 2017.

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be submitted to the Administrator using one of the following options:

Shell DEPs Online (Users with access to Shell DEPs Online)	Enter the Shell DEPs Online system at https://www.shelldeps.com Select a DEP and then go to the details screen for that DEP. Click on the "Give feedback" link, fill in the online form and submit.
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DEP Standard Form (other users)	Use DEP Standard Form 00.00.05.80-Gen. to record feedback and email the form to the Administrator at standards@shell.com .

Feedback that has been registered in the DEP Feedback System by using one of the above options will be reviewed by the DEP Custodian for potential improvements to the DEP.

1.7 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

1.8 NON NORMATIVE TEXT (COMMENTARY)

Text shown in italic style in this DEP indicates text that is non-normative and is provided as explanation or background information only.

Non-normative text is normally indented slightly to the right of the relevant DEP clause.

2. RESERVOIR REQUIREMENTS FOR PRODUCED WATER BASED WATERFLOOD AND WELL DISPOSAL

2.1 BACKGROUND

1. When defining the design basis for produced water waterflood or produced water well disposal, the following factors should be addressed and mitigated using specific studies:
 - a. Injectivity impairment and formation damage
 - b. Scaling (fluid-fluid compatibility)
 - c. Reservoir souring

Produced water discharge to sea does not result in any reservoir impact and is not covered by this section. Scaling assessments related to a produced water discharge to sea scheme are conducted as part of normal flow assurance assessments without any specific considerations due to produced water re-injection or well disposal.

These general assessments will have a direct impact on water quality and the system design, specifically equipment selection and production chemicals.

2.2 INJECTIVITY IMPAIRMENT AND FORMATION DAMAGE

The sustainable reservoir injectivity is not only dependent on reservoir properties, but also on the specific characteristics of the injected produced water.

1. As a minimum, definition shall be provided on the following injected water characteristics:
 - a. Suspended solids levels and size distribution in the injected water;
 - b. Dispersed oil-in-water levels in the injected water;
 - c. Type of solids (scale, sand, silt and/or schmoo);
 - d. Temperature of the injected water at the injection well.
2. The reservoir engineer and production technologist shall determine sustainable well injectivity flow rates into a reservoir as a function of the characteristics of the injected water.

Pressure surges in the water injection system, resulting from (sudden) flow variations also affects injection wells. Flow variation could be due to shut-in of the injection well, closure of other valves along the water injection system, or start-up/trip of the injection pumps.

The pressure surge travels along the injection system and may even cause solids from the reservoir (unconsolidated sands) to migrate towards the near well bore area, resulting in injectivity impairment, or into the well itself.

3. The production technologist, flow assurance engineer and concept engineer shall assess the consequences of pressure surges along the water injection system, i.e. integrated system of injection pump, flow lines and wells, including migration of fines into the near well bore area.
4. This assessment shall include the influence of injection pump trips/stops and operating procedures that can result in low pressures and unintended cross flow between injection wells.
5. System design and operating procedures shall prevent pressure surges that result in migration of fines into the near well bore area.

2.3 SCALING

Produced water reinjection and well disposal related scaling issues are:

- *Self-scaling potential of the injected water,*
 - *Scaling due to incompatibility of the injected water with the formation water;*
 - *Self-scaling potential of the produced fluids following water breakthrough;*
 - *Scaling potential due to incompatibility of produced water with other water sources for water flood (e.g., seawater, aquifer water)*
1. The production chemist/flow assurance engineer shall conduct a scaling assessment to identify scaling potential and severity of scaling.
 2. Options to mitigate and/or control scaling shall be defined.
 3. The scaling control strategy shall be decided upon by the project team, based on a lifecycle cost evaluation for the applicable project conditions.

2.4 RESERVOIR SOURING

Produced water based water flood and well disposal can result in reservoir souring.

1. The souring potential assessment, see DEP 25.80.10.18-Gen., shall be executed to identify if any reservoir souring is expected.
2. When the souring potential assessment concludes that there is a risk of reservoir souring, the production chemist (souring expert) shall predict the H₂S concentration in the reservoir and the produced reservoir fluids as a function of time.
3. Options to mitigate and/or control reservoir souring shall be defined.
4. In case nitrate injection into the injected water is selected for souring control, the corrosion assessment and materials selection shall evaluate the increased corrosion risk of the injection system.
5. The souring control strategy shall be decided upon by the project team, based on a lifecycle cost evaluation for the applicable project conditions.

3. BASIS FOR WATERFLOOD, WATER DISPOSAL AND SURFACE DISCHARGE TO SEA DESIGN

3.1 GENERAL

1. The basic input data listed in Table 1 shall be specified as a function of the produced water destination.

This data is required for the design for the produced water system.

For some projects a mix of produced water destinations may be appropriate resulting in multiple design cases.

2. The environmental engineer shall specify additional produced water quality requirements as applicable.

Legislation may set additional quality requirements for produced water re-injection or well disposal.

Requirements for surface discharge to sea are generally covered by legislation and the Shell HSSE & SP Control Framework HSSE Environment Manual (Specification for Discharge to Water Minimum Requirements).

3. If the basic input data does not provide a limit for dispersed oil-in-water content, the oil-in-water specification on which the produced water treatment system is designed shall be defined by the concept engineer based on cost/benefit analysis of additional oil recovered.
4. When multiple cases are defined by the reservoir engineer, these may include (sea) water as source water; an integrated subsurface-surface-wells assessment shall compare these cases and select the optimum concept.
 - a. The integrated assessment shall as a minimum address economic parameters (cost, production and schedule), operability and quantified risks.

Table 1 Basic input data required for design of produced water system

Design requirement	Produced water destination		
	Produced water re-injection	Well disposal	Surface discharge to sea
Water injection volume	√	√ Note 2	Not applicable
Produced water forecast	√	√	√
Number and location of injection wells	√	√	Not applicable
Injection flow rate per well	√	√	Not applicable
Injection pressure	√	√	Not applicable
Water quality (Note 1)	√	√	√
Design life/Expandability	√	√	√

NOTES: 1. Including disposal temperature

2. Water injection volume for disposal may be limited by non-producing reservoir or aquifer maximum pressure

3.2 WATER INJECTION VOLUME

1. Requirements for water injection volumes on an annual basis shall be defined by the reservoir engineer in terms of production/injection forecasts.
2. A Reliability, Availability and Maintenance (RAM) study shall be documented to assess the availability for a given injection system, taking into account the specific availability issues associated with all elements in the produced water treatment and injection system including the sparing of critical elements, as well as alternative water source treatment and injection system.

3. The RAM study shall:
 - a. utilize country, field and organisational specific data on equipment and system availability, where available;
 - b. consider subsurface, wells, infrastructure and process and utility system constraints.
4. A design margin (or surge factor) should be included on the fluid flowrate, to provide an allowance for surging and uncertainties in the basic data.
 - a. The surge factor used should be confirmed by the Principal.

3.3 PRODUCED WATER FORECAST

The produced water forecast for a reservoir, or field is dependent on specific reservoir characteristics that at the onset of a design are uncertain. The uncertainty associated with these parameters could result in large variations in the produced water forecast, particularly in terms of the onset and rate of increase of produced water.

The produced water forecast in case of produced water re-injection is affected by the amount of water injected and quality of the injected water.

1. The produced water forecast(s) shall consider the impact of the uncertainties in reservoir characteristics, the selected recovery mechanism and the water quality.

3.4 NUMBER AND GEOGRAPHICAL LOCATION OF INJECTION WELLS

The number and geographical location of injection wells, in combination with the injection pressure, is relevant for the design of the injection pumps and the distribution piping network.

1. The number and geographical location of the injection wells shall be defined.
2. The impact of reservoir geometry, sweep, well injection flow rates and water quality should be considered.

3.5 WELL INJECTION FLOWRATE AND PRESSURE

The injection pressure is defined by the injection regime, and in case of fractured injected, by the maximum allowable fracture growth.

1. The production technologist shall define the following:
 - a. The range of the well injection flow rates (minimum, normal and maximum).
 - b. The minimum required injection pressure over the design life at maximum well injection flow rate,
 - c. The maximum allowable injection pressure.
2. The maximum allowable injection pressure shall not exceed the pressure that corresponds to the limit defined by the Top Seal Integrity; refer to DEP 25.80.10.22-Gen.
3. The injected water flow rate in each well shall be controlled in terms of rate and pressure.
4. The allocated volume of water injected into a well shall be recorded by appropriate metering

3.6 PRODUCED WATER QUALITY

1. Specification of the injected or discharged produced water quality shall, as a minimum, include the parameters listed in Table 2.
2. The water quality requirements shall be defined including tolerable excursions (including frequency and duration) of specification parameters in Table 2.

The water quality specification for produced water re-injection and well disposal is defined by the production technologist at the entrance of the reservoir (well bore). Contaminants such as corrosion products, scale, biofouling, formed between the last treatment step and the well bore deteriorate the injected water quality.

3. The concept engineer shall assess impact of distribution and injection system downstream of the last treatment step on the water quality.
4. The water quality requirements shall include the mitigations arising from the assessments for injectivity impairment and formation damage (2.2), scaling (2.3) and souring (2.4).

Table 2 Produced water quality specification parameters

Parameter	Specification	Produced water destination		
		Produced water re-injection	Well disposal	Surface discharge to sea
Suspended Solids	Maximum level	√ ^M (ppmv)	√ ^M (ppmv)	√ ^P (mg/l)
	Maximum particle size	√ ^M	√ ^P Note 4	Not applicable
Dispersed oil-in- water	Maximum level	√ ^M (ppmv)	√ ^M (ppmv)	√ ^M (mg/l)
Dissolved HC	Maximum level	Not applicable	Not applicable	√ ^P Note 2
Bacteria count	Maximum	√ ^M	√ ^M	Not applicable
Temperature	Maximum	√ ^P	√ ^P	√ ^P
	Minimum	√ ^P	√ ^P	Not applicable
Chemicals	Maximum level	√ ^P Note 1	√ ^P Note 1	√ ^P
Ionic composition Note 3	Maximum level	√ ^P	√ ^P Note 4	√ ^P
	Minimum level	√ ^P	√ ^P Note 4	Not applicable

√^P = possible requirement

√^M = mandatory

- NOTES:
1. Country or regional legislation may set requirements for maximum level of production chemicals injected into reservoirs and aquifers.
 2. For surface discharge to sea, the requirement for specification of dissolved hydrocarbon content depends on the legislation. Typically, methods described by the legislation for Oil in Water (OIW) analysis do not discriminate between dispersed and dissolved hydrocarbons.
 3. For specific ions
 4. This may be relevant for specific well disposal reservoirs that require matrix injection. It is generally not relevant as most well disposal is under fracture conditions.

3.7 CHARACTERISTICS OF FEED WATER

The characteristics of the produced water feed streams and reservoir fluids are field/project specific.

Over the field life, the reservoir fluids characteristics and more specifically the produced water characteristics may change as a result of:

- *injected water breakthrough*
- *aquifer water ingress*
- *injected gas breakthrough*
- *change in reservoir pressure*
- *change in reservoir temperature*
- *reservoir souring (2.4)*

In addition certain non-routine operations, such as well clean-up, may result in temporary excursions of the "normal" produced water characteristics.

1. A relevant water quality characterisation shall be done prior to selection of any equipment that may impact performance or integrity.
2. The concept engineer shall define the characteristics of the various produced water streams.
3. The production chemistry discipline shall define the sampling, analysis and interpretation of the analysis.

Creating a representative droplet size distribution in the laboratory is very hard, if not impossible. Also on-site droplet size distributions are bound to be non-representative, as it is affected by the sampling. Subsequent time lags will render the analysis even more unreliable.

4. Droplet size distribution analysis prepared and analysed in laboratory based on mimicking the actual operating conditions should only be used for relative comparison between the various cases analysed and should not be interpreted as the actual droplet size distribution for a specific condition evaluated.
5. As a minimum, the characteristics listed in Table 3 shall be defined.
6. The potential variation as a result of the chosen recovery scheme shall be taken into account in the characterisation of produced water streams.
7. The uncertainty associated with key produced water characteristics shall be considered to ensure that robust produced water treatment system is selected.