

Understanding of the Co-deposition of Calcium Sulphate and Calcium Carbonate Deposition in ESP

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ABSTRACT

Electric Submersible Pump (ESP) in oilfield is prone to scale deposition, largely due to temperature increases by motor heating, and turbulent flow and high shear inside of pump. In this work, the formation of calcium sulphate and calcium carbonate were studied under a range of conditions that could possibly be encountered in ESPs. The produced water chemistry changes from 100% formation water to mixed formation water and injected seawater over time. The scaling tendency and potential mass deposition are simulated using a thermodynamic prediction model. Dynamic scale loop tests were carried out to study the calcium carbonate, calcium sulphate and co-deposition under field conditions. The results indicate that the risk of calcium carbonate scale at the initial stage of production in both downhole and ESP. With the breakthrough of seawater, the risk of calcium sulphate scale increases, and harsh calcium sulphate scale could form in ESP. This study also suggests that the interference between CaSO_4 and CaCO_3 formation is minor under the test conditions. These findings will be used to develop the scale mitigation strategies.

Keywords: scale, calcium carbonate, calcium sulphate, ESP

INTRODUCTION

Scale formation is one of the flow assurance problems encountered in the oil and gas industry. It can deposit from reservoir, downhole tubing to topside facilities. Once formed, it could have

a significant impact on production, including tubing and valve blockage, interference of well intervention, and even well abundance.^{1, 2}

Calcium carbonate and calcium sulphate are two common scales formed in oilfields. Both scales could form when the saturation of scaling water increases to a certain level due to the change of temperature, pressure, pH, etc. Calcium sulphate also could precipitate when mixing of incompatible waters, such as the injected seawater which contains high concentration of sulphate ion mixed with and calcium-rich formation water. Calcium sulphate can form in the reservoir, near wellbore area, production tubulars, and topside facilities.³ Calcium sulphate dihydrate (gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is commonly precipitated at low temperature and calcium sulphate (anhydrite, CaSO_4) often precipitated at elevated temperatures and pressures.⁴

Scale could be more favor to deposit at specific locations like electrical submersible pump (ESP), downhole safety valve, choke valve, etc. Electrical submersible pump (ESP) is one of the most common artificial lift applications in the oil wells. It consists of multiple centrifugal pump stages mounted to a submersible electric motor. The motor generates heat and cause the temperature increase of inner surface.⁵ The temperature is a major driving force for calcium carbonate and calcium sulphate scale formation. Figure 1 showed the solubility of common scales as a function of temperature. With increase of the temperature, the solubility of calcium carbonate and calcium sulphate decreases. Higher temperature also accelerates the scaling kinetics. Therefore, both calcium carbonate and calcium sulphate scale are more likely to form in the ESP due to the increase of surface temperature inside of ESP.

In this paper, calcium sulphate and calcium carbonate precipitation were studied under a range of conditions that could possibly be encountered in ESPs. Seawater injection is also used for pressure support and production enhancement in this field. The produced water chemistry changes from 100% formation water to mixed formation water and seawater over time during the life span of production.

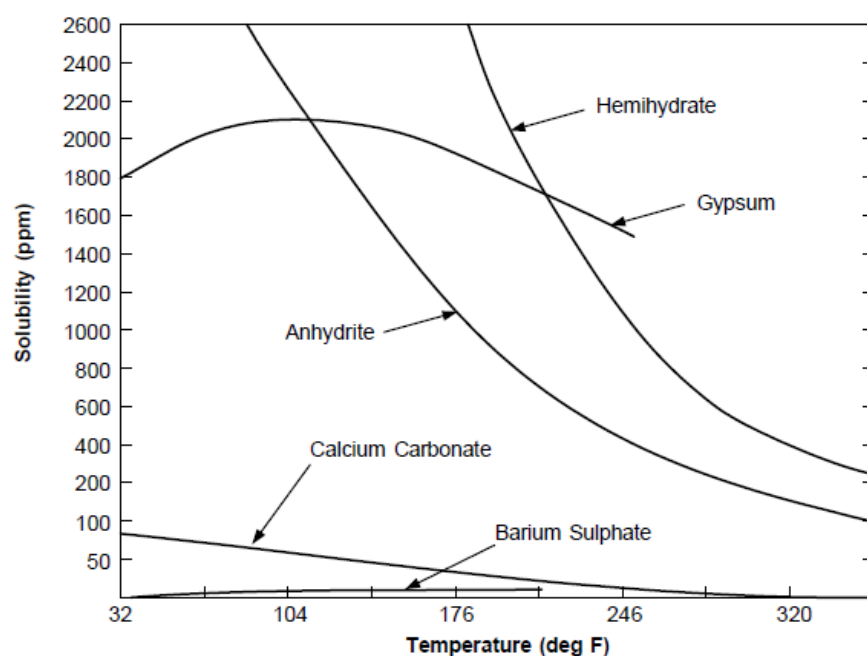


Figure 1: Solubility of common scales as a function of temperature.⁶

EXPERIMENTAL METHODOLOGIES

CaCO₃ and CaSO₄ scale risk assessment

Thermodynamic prediction is carried out to assess the scale formation risk. It provides both scaling tendency (saturation ration) and deposition mass. The prediction was performed using one of the well-recognized industry standards, the ScaleSoftPitzer program, Version 2019. It should be noted that scale predictions can only be used to provide a guide to the likely nature and extent of the scaling challenge, and to investigate the impact of a process change on the likely severity of scaling.

The formula for saturation ratio is given in Equation 1.

$$S_a = (a_1 \times a_2) / K_{(P,T)}$$
$$a = \gamma \times C$$
(Equation 1)

where

S_a is the saturation ratio and α is the activity of the separate species. α_1 and α_2 are the activity of scaling cation and anion in the solution respectively. K is called the solubility product, which depends on the pressure (P) and the temperature (T).⁷ C is the concentration of scaling ions in the solution. γ is the ionic activity coefficient.

Scale can occur at point where super-saturation is generated. A supersaturated solution is the primary cause of scale formation and the concentration of ions are above their equilibrium concentration. The degree of saturation, in term of scaling saturation ratio S_a , is the driving force for the precipitation reaction and implies the possibilities for scale precipitation. Guideline values for the interpretation of SR values are provided in Table 1. It is the case that different programs may interpret the level of risks slightly differently.

Table 1
Interpretation of Scale Prediction Results

SR	Interpretation
< 1	Under-saturated for the scale type. Non-scaling.
1 – 3	Slightly supersaturated. Likelihood of scale formation is marginal.
3 - 10	Scale likely, but should not be severe.
10 – 100	Scale almost certain to occur. Expected to be strongly scaling.
> 100	Severe scaling likely.

Dynamic loop test

Dynamic scale loop tests were performed to detect calcium carbonate formation in 100% formation water, and the worse calcium sulphate scaling scenario during seawater breakthrough based on predictions. The water chemistries of formation water and seawater are summarised in Table 2.

Table 2
Brine Chemistry for Scaling Tests and Prediction

	Formation water (FW) (mg/l)	Seawater (SW) (mg/l)
Na ⁺	643000	21800
Ca ²⁺	14000	600
Mg ²⁺	4000	2000
K ⁺	150	600
Sr ²⁺	200	10
Cl ⁻	135000	37000
HCO ₃ ⁻	300	150
SO ₄ ²⁻	1000	5300

A flow diagram of the dynamic scale loop apparatus is shown in Figure 2. The test consists of the injection of two scaling test brines, anion and cation, at equal rates into the apparatus. Both brines pass into heating coils within the oven and are heated to the test temperature. At a T-junction, the brines mix and flow into the capillary scaling coil. The differential pressure (ΔP) is measured across the scaling coil and rises once scale deposited on the surface of scaling coil. Differential pressure (ΔP) is recorded as a function of time.

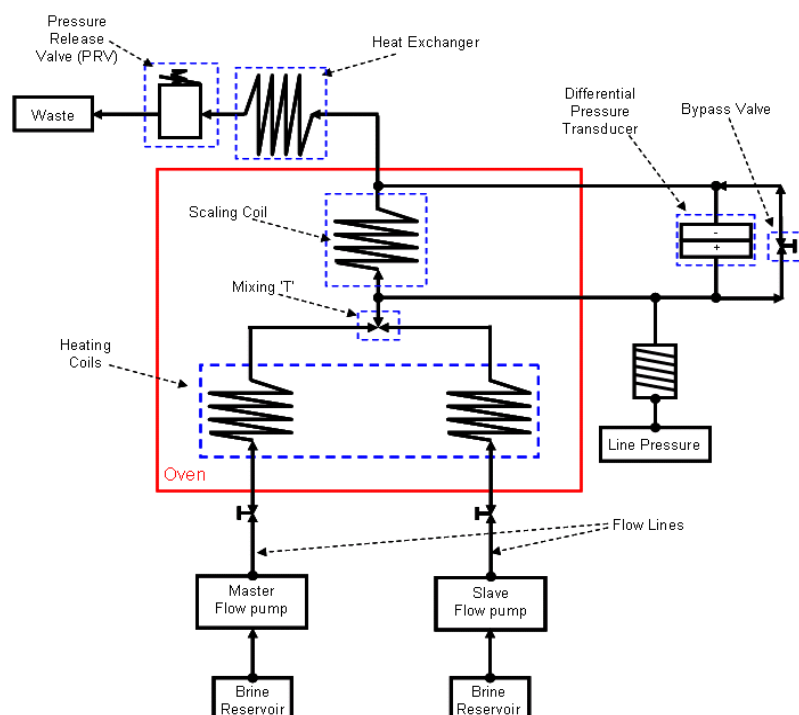


Figure 2: Flow diagram of the dynamic loop system.