

Integrated Scale Management for Geothermal

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ABSTRACT

Operational challenges such as scaling can severely affect geothermal heat production. Therefore, prediction, control and mitigation of these operational issues is key to a reliable energy supply. The prediction of processes reducing production, such as scaling and corrosion, is being done globally without considering the local changes in flowing conditions (e.g. in pumps, filters, separators). Most scaling issues are reported in the wellbores and top-side facilities and are caused by chemical reactions in the geothermal water that occur when the water is subjected to changes in temperature and pressure. Therefore, an integrated modelling approach is proposed to assist geothermal operators in increasing their energy production by limiting scaling.

The goal of the proposed integrated modelling is to combine the knowledge and models of both subsurface and surface to better evaluate the scaling potential. This approach includes modelling of flow, thermodynamics and scaling chemistry. The model extends to the reservoir, production well and top-side installations of a geothermal doublet. The integrated workflow is tested on a Dutch geothermal site targeting the Delft sandstone. The integrated modelling approach showed that the impact of changes in operational settings (e.g. tank pressure, pumping power, etc.) on scaling potentials in the whole chain of geothermal doublets can be better described and quantified. Such a tool could be used to predict and give insights in location and amount of scaling in the heat loop as a means to optimize the production from geothermal doublets.

1. INTRODUCTION

A key operational challenge in geothermal energy production is corrosion and scaling which restrict flow and cause the decline of productivity and injectivity over time. Although scaling and corrosion have been dealt with since the beginning of oil, gas and geothermal production, a recent review article on “Operational issues in Geothermal Energy in Europe” (Schreiber et al, 2016) highlighted the operational barriers caused by scaling, corrosion, gas content and poor injectivity while stating that there is still a lack of solutions.

Mineral scaling is reported to occur in geothermal systems targeting many different geological reservoirs, under a wide range of temperature and chemical conditions. The here reported work is a part of the Perform project (Wasch et al, 2019), which focusses on low enthalpy geothermal systems of the Permian Basin (North Germany, Belgium, Netherlands, Denmark) and in the Upper-Rhine Valley. For the Dutch case we study doublets in the West Netherlands Basin (WNB). Mineral scales originating from these clastic geothermal systems with temperature below 100 °C could be carbonates, silica polymorphs, metal compounds (oxides, hydroxides, sulphides, sulphate) and clays (Eggeling et al., 2013, Regenspurg et al., 2010, Regenspurg et al., 2015, Wanner et al., 2017).

The integrated models are applied to a geothermal system that co-produces hydrocarbons (mainly methane) and to a lesser extent CO₂ with the targeted hot water. The West Netherlands basin is well known for its oil and gas fields and hydrocarbon charging resulted in oil, gas and CO₂ dissolution in the water even when no hydrocarbons traps are present. Upon production, the water partially degasses when the pressure decreases from the reservoir to the surface facilities causing the gas solubility to decrease. After gas exsolution from the water, a new chemical equilibrium must be formed which may cause mineral precipitation within the geothermal installation. CO₂ degassing or exsolution is well known to increase the pH of the water, causing especially carbonates to precipitate (Alt-Epping et al., 2013, Wasch, 2014). We therefore focus on calcite precipitation for the geochemical modelling of the impact of pressure reduction on scaling potentials. For the cooling process, we selected barite as most likely precipitating mineral based on the before mentioned literature and the composition of the produced geothermal water. The geochemical models on calcite and barite precipitation are coupled to multiphase flow simulators to include the detailed pressure, temperature and flow conditions and their effect on scaling.

2. APPROACH

Integrated scale management encompasses the full circle of produced geothermal water flow through the production well, top-side installations, the injection well and into the reservoir (Fig. 1). The approach

connects multiphase flow in wells and top-side (e.g. in-house wellbore and topside models or commercial models like OLGA and LedaFlow) with geochemical (e.g. PHREEQC or OLI-ScaleChem) models. To include phase changes, a thermodynamics model, such as PVTsim, can be required. In this approach, chemical and physical changes of the geothermal fluid as a result of different pressure and temperature conditions in the geothermal loop could be predicted. Finally a coupling could be made to the reservoir, to assess the effect of injecting a chemically and physically altered water (e.g. TOUGHREACT).

The models solving the flow properties in wellbores and top-side facilities provide information on local pressures, temperatures and phase fractions (gas and liquid). Such information is coupled to the geochemical models computing scaling potentials at the calculated conditions. In case the geochemical model predicts the precipitation of a mineral, the precipitated amount will be dropped out of the geothermal brine composition and the following geochemical calculation is performed using the updated geothermal fluid compositions. The workflow is applied to a Dutch doublet to showcase the ability of integrated modelling to capture the processes involved in scaling and injectivity decline and to highlight its use in operational advice.

2.1 Software

The transient multiphase flow model LedaFlow was used as the flow solver for the wells and top-side facilities. This software is widely used for oil and gas applications. In the flow solver, the conservation equations of mass, momentum and energy are computed in 1D along the flow path. Phase separation due to changes in PT can be included in this model. To include phase changes, a link to the thermodynamics model PVTsim was applied. PVTsim is a simulation program developed by Calsep which uses an equation of state (EoS) to calculate properties of (mixture) of fluids. The EoS used is the SRK Peneloux. The output of these simulations are fluid properties such as phase fractions, density, viscosity, etc.

For the selected pressure and temperature points in the flow path as calculated with the wellbore and top-side models and using the gas exsolution calculated with

thermodynamic models, the occurrence of scaling can be predicted with geochemical modelling tools. To simulate the scaling potential as a result of cooling and depressurization and CO₂ exsolution out of the geothermal brine we used PHREEQC. PHREEQC version 3 is a computer program written in the C and C++ programming languages that is designed to perform a wide variety of aqueous geochemical calculations (Parkhurst and Appelo, 1999). Several thermodynamic databases are available for PHREEQC and can be user selected, for this project we used the Ilnl and pitzer databases (downloaded with PHREEQC v3. <https://www.hydrochemistry.eu/ph3/index.html>). With PHREEQC the scaling potential can be defined as the saturation index (SI) or amount of mineral precipitation required to re-establish the chemical equilibrium of the geothermal water. A SI value above 0 indicates that a mineral is oversaturated and hence a tendency to precipitate.

Coupling with reactive transport models and THMC, thermo-hydro-mechanical-chemical models (e.g. TOUGHREACT, Xu et al., 2006 and Flac3d, Gan and Elsworth, 2016) is ongoing and not covered in this paper.

2.2 Constraining the gas content

Available water and gas composition measurements are rarely ideal with the samples taken bottom hole where gas and water are in mutual equilibrium, oxygen free and no precipitation has yet occurred. In our case, the gas is sampled at the top-side separator and the water at a different location on the top-side. At the oil and gas separator the fluid is partially depressurized and some gas remains in solution. Sampling depressurized gas results in an underestimation of the CO₂ fraction in the gas. This is caused by the pressure dependence of the gas composition, with a high fraction of CH₄ exsolving at the onset of degassing and a larger fraction of the more soluble CO₂ exsolving at lower pressures. For example in another doublet, 8 mol% of CO₂ was measured in gas sampled at the separator, whereas 20 mol% of CO₂ was measured in the flashed gas from a bottom hole sample. Without a bottom hole sample it is difficult to know the exact amount of CO₂ that is initially dissolved in the water but this has to be corrected for.

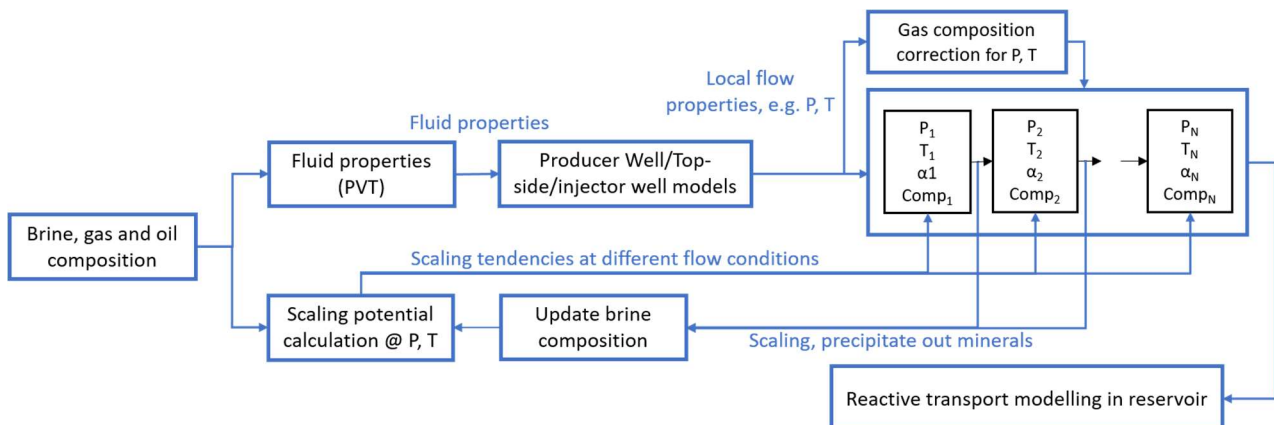


Figure 1: Workflow of the integrated modelling approach.

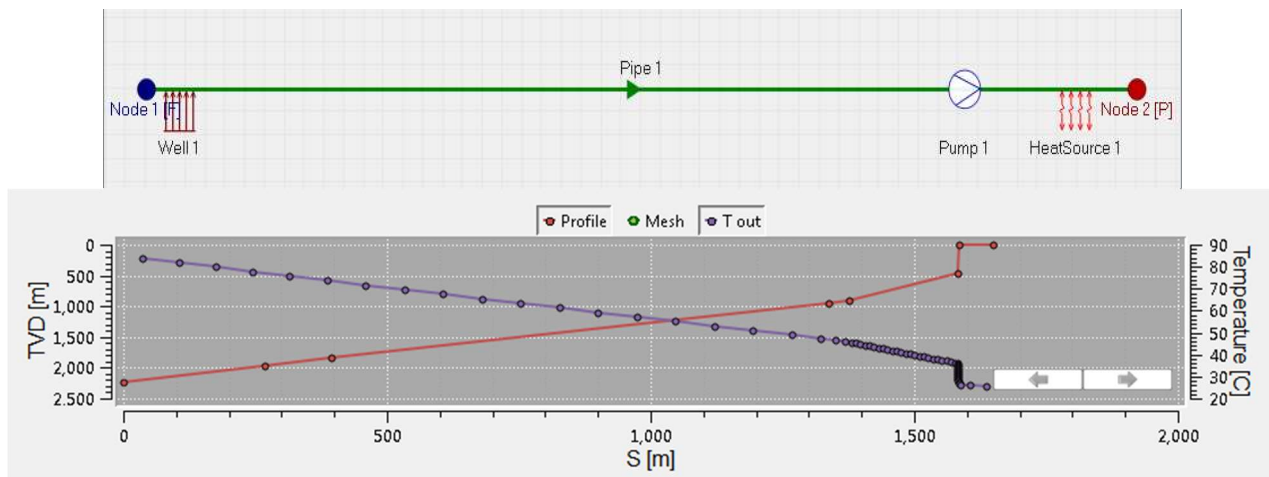


Figure 2: Schematic of the well model, well trajectory and temperature profile.

PHREEQC is not suited to deal with gas mixtures and their PVT behaviour and cannot be used to calculate the dissolution and exsolution of CO_2 and CH_4 at different pressures and temperatures. We used PVTsim to obtain the missing compositional data, when satisfying two constraints, taking the following calculation steps:

1. Take measured gas composition (90.2 mol% CH_4 , 2.473 mol% CO_2)
2. Add H_2O until at 1 bar, 20 °C the vapour/liquid ratio is 1 at tank pressure (phase fraction of 1 is measured in the field)
3. Add CO_2 until at 3 bar, 70 °C the CO_2 mol% in the vapour is equal to the measured composition
4. Repeat 2 and 3 until both are valid.

After constraining the initial system we used PVTsim to calculate the fractions of CH_4 and CO_2 in gaseous and aqueous phase at different pressure and temperature points, as an input for the multiphase flow models.

2.3 Model input

In this study, only the scaling in the producer well and top-side facilities was considered. An example well geometry of a typical geothermal well was used, as shown in Fig. 2. The production well is a deviated well with the MD of approximately 3 km and TVD of 2.2 km. The completion consists of three zones; a lower zone with a length of 700 m and an inner diameter of 103 mm, a middle zone with a length of 1.3 km and an inner diameter of 160 mm and the top zone with a length of 1 km and an inner diameter of 225 mm. The well is producing from two zones of each around 100 meters in length and with an ESP (Electrical submersible pump) located at the depth of around 500 m (MD). At the top side a heat exchanger (HEX) was added to reduce temperature to 30 °C, which is a typical injection temperature. Reservoir and flow conditions are listed in Table 1. The chemical composition of the measured water sample is listed in Table 2. The pH of the water was 6, measured at lab conditions.

Table 1: Parameters of the reservoir, well and inflows for the simulations

Parameter	Value	Unit
Reservoir pressure	200	bar
Reservoir temperature	75	°C
Inflow parameter	0.85	kg/(m s bar)
ESP efficiency	0.8	-
Flow rate	30	kg/s

Table 2: Fluid composition (main components)

Element	Value (mol/l)
Na	1.72
Mg	3.94E-02
K	5.12E-03
Ca	1.08E-01
Fe	1.07E-03
Sr	4.68E-03
Ba	9.88E-05
C	3.69E-03
Cl	2.13
S	8.33E-04
Si	4.52E-04

3. MODEL RESULTS

Two scenarios were simulated using the wellbore and top-side model for two different tank pressures of 2 and 5 bar. The results of the simulations are shown in Fig. 3. The pressure, temperature and gas mass flow rates were compared for the two tank pressures. The pressure profile shows that the pressure in the wellbore decreases from downhole to the surface and that for different tank conditions, the pressure changes especially downstream of the ESP. There is a slight deviation in the temperature for a different tank pressure. However, the gas release rate is significantly different when changing the tank pressure. This is mainly due to changes in the pressure along the tubing resulting from changing the tank pressure. This will affect the amount of gas exsolution due to the pressure

dependence of the CO₂ solubility. It is important to note that for a different tank pressure, the same boosting pressure was applied by ESP and thus the flow rates of the geothermal fluid were not kept constant. In other words, the flow rate of the geothermal fluid is lower at a higher tank pressure.

The results obtained with the different models are combined in Table 3 for a tank pressure of 5 bar and in Table 4 for a tank pressure of 2 bar. For both the 2 and 5 bar case, it is predicted that gas exsolves due to the initial pressure drop during production but that the gas partially dissolves again further up in the well (due to pressure jump along the ESP). With further pressure decrease reaching the surface, more and more gas exsolves, indicating that there is already free gas in the well before the gas separator tank.

Although some gas is already exsolved, the PHREEQC model shows that only in the 2 bar tank case calcite precipitation is to be expected (Table 4). Calcite starts to precipitate before the pressure decreases to 2 bar, but the bulk of calcite precipitates at 2 bar. For the 5 bar tank pressure case, the saturation index of calcite

remains negative throughout the system (Table 3). This indicates a tendency to dissolve instead of precipitate, although the SI does come close to 0 when reducing the pressure to 5 bar. The pH of the brine decreases with CO₂ exsolution but is buffered by calcite formation so that the final pH remains close to 6. Note that PHREEQC predicts more minerals to be oversaturated but these are not considered to precipitate due to their slow reaction rates.

Barite is already over saturated at reservoir conditions and we choose to maintain this oversaturation during all model steps. When it becomes more saturated than the SI value of 0.1, barite is modelled to precipitate. Precipitation only happens during cooling since barite is not pH dependent like calcite (Table 3 and Table 4). With the slight temperature changes during production a small amount of barite is predicted, but the bulk of barite scaling is predicted at the lowest temperature at 30 °C when heat has been extracted. Barite precipitation is kinetically controlled and hence it may not precipitate in the geothermal system at the heat exchanger, but could cause scaling in the injection well or in the reservoir.

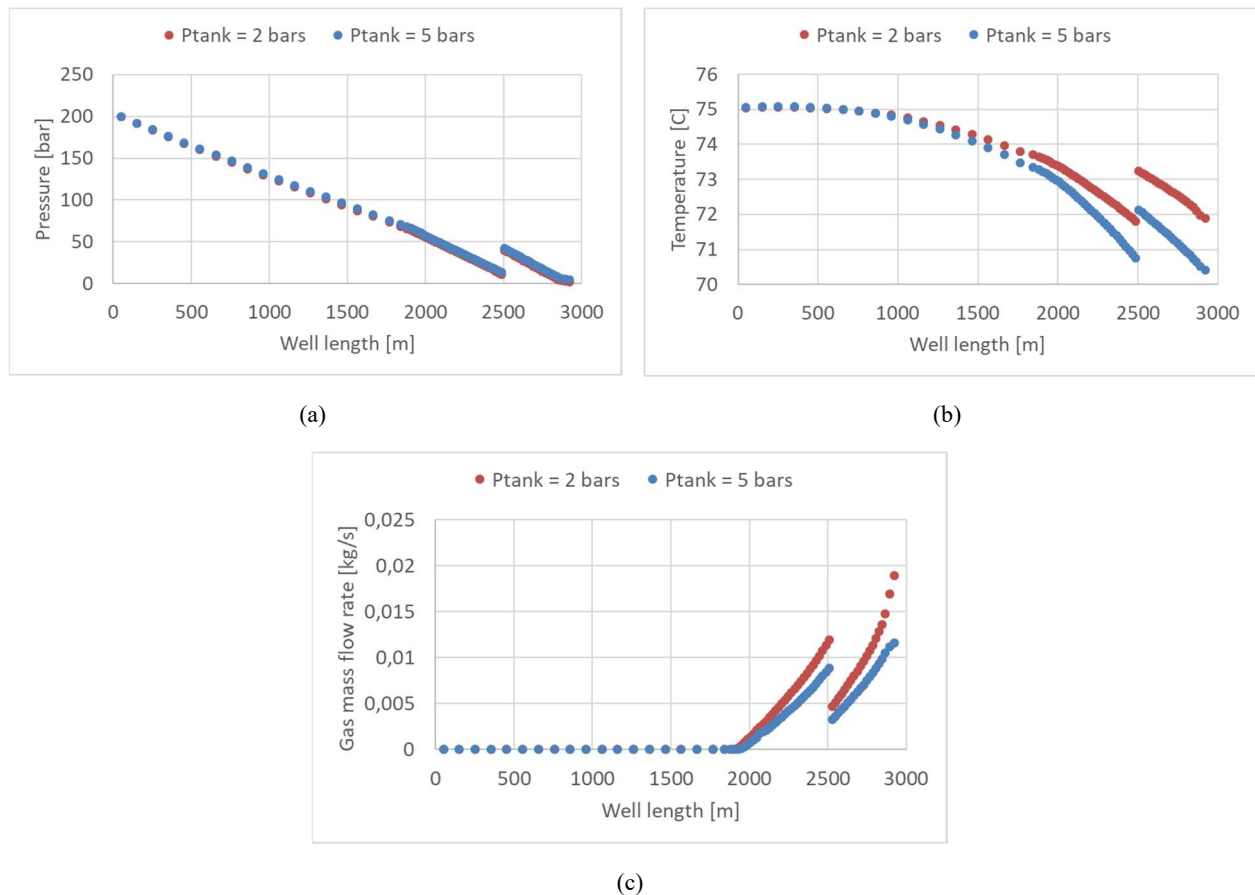


Figure 3: Results of wellbore and top-side simulations for different tank pressures (a) pressure, (b) temperature and (c) gas mass flow rate profile along pipe length.

Table 3: Model results of the 5 bar tank pressure case. The PT data comes from LedaFlow (wellbore flow model), amounts of CO₂ present are derived with PVTsim and the pH and mineral data is calculated with PHREEQC, the last point (@HEX) corresponds to the cooling at the heat exchanger.

Pipe length [m]	Gas volume fraction	T (°C)	P (bar)	CO ₂ as gas (mol)	CO ₂ in 1 liter brine (mol)	Dissolve /exsolve CO ₂ gas (mol)	pH	Calcite (mol/l)	Barite (mol/l)	SI Calcite	SI Barite
50	0	75.06	199.8	0	1.85E-3		5.70	0	0	-0.14	0.09
2486	0.05	70.76	13.41	3.3E-4	1.52E-3	-3.3E-4	5.80	0	9.8E-6	-0.09	0.1
2526	0.01	72.05	40.25	7.1E-5	1.78E-3	2.6E-4	5.75	0	0	-0.13	0.01
2746	0.04	71.18	17.72	2.4E-4	1.61E-3	-1.7E-4	5.79	0	0	-0.10	0.09
2846	0.1	70.73	7.88	5.4E-4	1.31E-3	-2.9E-4	5.85	0	7.1E-8	-0.05	0.1
2921	0.14	70.41	5.07	7.4E-4	1.11E-3	-2.1E-4	5.90	0	7.6E-7	-0.004	0.1
@HEX		30	5.07				5.85	0	7.1E-5	-0.65	0.1

Table 4: Model results of the 2 bar tank pressure case. The PT data comes from LedaFlow (wellbore flow model), amounts of CO₂ present are derived with PVTsim and the pH and mineral data is calculated with PHREEQC, the last point (@HEX) corresponds to the cooling at the heat exchanger.

Pipe length [m]	Gas volume fraction	T (°C)	P (bar)	CO ₂ as gas (mol)	CO ₂ in 1 liter brine (mol)	Dissolve /exsolve CO ₂ gas (mol)	pH	Calcite (mol/l)	Barite (mol/l)	SI Calcite	SI Barite
50	0.00	75.05	199.7	0			5.70	0	0	-0.13	0.09
2486	0.07	71.81	11.07	4.0E-4	1.45E-3	-3.98E-4	5.82	0	7.3E-6	-0.06	0.1
2526	0.01	73.18	37.84	8.1E-5	1.76E-3	3.17E-4	5.76	0	0	-0.11	0.09
2746	0.05	72.55	14.91	2.9E-4	1.55E-3	-2.16E-4	5.80	0	0	-0.07	0.09
2846	0.16	72.2	5.06	7.5E-4	1.09E-3	-4.57E-4	5.89	3.2E-5	0	0	0.09
2921	0.35	71.9	2.15	1.2E-3	6.50E-4	-4.44E-4	5.93	1.3E-4	0	0	0.1
@HEX		30	2.15				5.88	0	7.5E-5	-0.67	0.1

3. CONCLUSIONS AND DISCUSSION

An integrated workflow for scaling management was proposed and tested on a representative geothermal system. The models have been tested for a Dutch doublet and were successful in mimicking the observed calcite scaling when the system was at 2 bar and the prevention of scaling when the system was kept at 5 bar (personal communication). This highlights the importance of an integrated modelling workflow for scaling prediction, management and mitigation. The developed scale management tools can help reduce operational costs by decreasing shut-down times for cleaning and filter changes.

Also the possibility of barite scaling was indicated by the model although that has not yet been found in the geothermal installation. This is probably due to the lower reaction rate of barite, but this can still mean that mineral precipitation is involved in reservoir scaling and injectivity decline.

The next steps of model development are including new/improved cost-effective technologies to avoid flow restrictions such as: removing reactants from solution, pH control and temperature optimization. This is part of the PERFORM project which overarching objective is to improve geothermal system performance, lower operational expenses and extend

the life-time of geothermal infrastructure. The developed workflow could be used as a support tool to assess new mitigation strategies (e.g. inhibitor injection or employing different type of filters) to optimize operational decisions. Additionally, uncertainties in the fluid sampling and compositions could have a significant impact on the outcome of the predictive models (Twerda et al, 2015). Thus, in the next step the impact of uncertainties in the fluid composition on the integrated model outcome needs to be quantified and assessed.

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