Task 1.3

Title

Hydrothermal heat exploitation and storage

Projects (presented on the following pages)

Deep Borehole Heat Exchanger for non-productive geothermal and hydrocarbon wells
L. Guglielmetti, A. Moscariello

Two pathways of SiO2 scaling inside a high-enthalpy geothermal power plant
D. B. van den Heuvel, E. Gunnlaugsson ,I. Gunnarsson, L. W. Diamond, L. G. Benning

SCCER SoE

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

SCCER-SoE Annual Conference 2017

In cooperation with the CTI

Energy
Swiss Competence Centers for Energy Research

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Commission for Technology and Innovation CTI

Deep Borehole Heat Exchanger for non-productive geothermal and hydrocarbon wells

Luca Guglielmetti and Andrea Moscariello

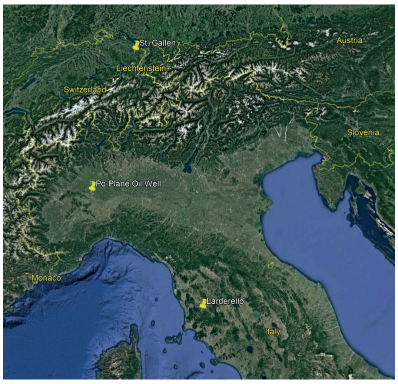
Earth Science Department, University of Geneva

ABSTRACT: Hydrocarbon and geothermal wells that ceased to produce or never produced might be retrofitted with heat extraction systems to either generate electricity or to produce heat for local mini-grid distribution.

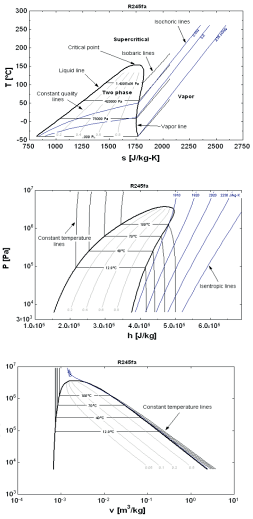
The goal of this very preliminary study is to evaluate the approaches published in recent literature in order to figure out how a co-axial deep wellbore heat exchanger where an organic working fluids extract heat from the host rock, vaporizes while descending and then flow towards the surface. Three case studies are considered in this study:

- Larderello (Tuscany, Italy) where, despite the high temperatures, several wells are non productive due to the presence of non-condensable gases
- Po Plain & Emilian Apennines (Northern Italy) wells which reached temperature up to 180˚C
- St. Gallen geothermal well which reached temperatures above 140˚C at 4250m in depth and was abandoned due to the presence of hydrocarbons.

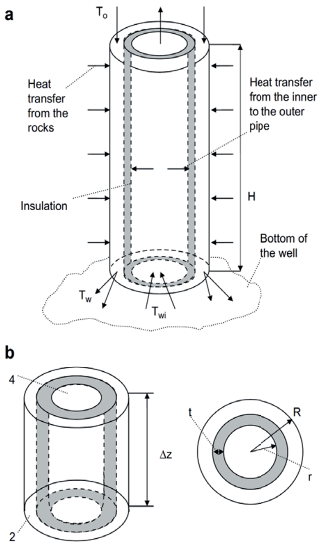
In the three cases, a comparison between different working fluids including water and organic fluids is presented to provide the optimal solution to increase the economic value of accessible end-of-lifewells producing heat or power using closed-loop and zero-emission small ORC power plants.



APPROACH: The general consensus is that coaxial heat exchanger (HE) may have some advantages over U-tube geometry in reducing resistance between the circulating fluid and the bore-hole wall. The main parameters that influence the performances of the heat exchanger are: **flow rate**, **geothermal gradient**, **bottom-hole temperature**, **inlet fluid temperature**, injection pressure, **fluid velocity**, and **insulation on the inner pipe**. Working fluids such as R125, R134a, R236a and **R245fa** are the most efficients for the geothermal power generation using abandoned wells. To produce electricity **Organic Rankine Cycle ORC** power plants have proven higher efficiency than Flash systems, for low temperature conditions. The techniques of heat extraction consists in a concentric double-pipe HE where a working organic fluid circulates in order to produce acceptable amount of thermal energy suitable for power production. The fluid circulates in the coaxial double-pipe HE, and heat transfer occurs without mass transfer. The fluid circulates in the well by means of a concentric double pipe. Cold fluid is injected into the well through the outer pipe, and the heat transfers from the hot rock to the fluid during injection. The hot fluid rises up through the inner pipe and is extracted at the wellhead. To avoid heat transfer between the inner and outer pipes, extruded thermal insulation surrounds the inner pipe. The computational models proposed in litterature take into account a transient model based on mass, energy, and momentum conservation equations for the well flow, and the simulation helps to determine the state of the fluid from injection to retrieval.



A: Ts Thermodynamic diagram for R245fa
B: Ph Thermodynamic diagram for R245fa
C: PV Thermodynamic diagram for R245f



(a) Schematic representation of the heat transfer in the well. (b) The scheme for direction of the flow and the top view of the pipes in the well. (from Davis, Michaelides, 2009)

Power output and commercial analysis: The three case studies show potentially favourable conditions for the installation of a BHE and the equipment of a ORC power plant for power production. The most favourable conditions are in Larderello thanks to the high temperature at rather shallow depth. The installed power capacity can range between 100 to 500 kw_{el} (assuming an natural upflow of the working fluid). The investment costs can range between 2 and 3.5 M$ depending on the depth of the well and the size of the ORC. These conditions can lead to the economic feasibility of the installations.

	Reservoir temperature (°C)	Reservoir Depth (m)	Gross Power Output (kWel)	Net Power Output (kWel)	Investment ($)	Incentives ($/MWel)	Break-even point (years)
Larderello	180	500	2410	500	$ 3,500,000	$ 275	5
Po Plane	184	6642	890	120	$ 2,500,000	$ 275	12
St. Gallen	145	4250	735	100	$ 2,000,000	$ 300	7

CONCLUSIONS: In this screening study, a geothermal power generation model based on transient formation heat transfer is presented for different areas accounting for accessible and abandoned geothermal wells in high and low enthalpy systems, and for closed-in oil wells with different ranges of well depths and geothermal gradients. The electricity generation using various organic fluids as working fluids is simulated. The electricity produced is little compared to standard geothermal power production mostly because of low heat transfer rates through the rock and reduced velocity and flow rate. However, if clusters of disused wells in old hydrocarbon fields could be connected together the geothermal power output could be realised with attractive economic screening values. A more detailed study, including different types of fluid and 3D well modelling can provide stronger results to support the development of this kind of system and will help optimizing the design of effective ORC power plants for this kind of projects.

REFERENCES:

Bu, X., Ma, W., & Li, H. (2012). Geothermal energy production utilizing abandoned oil and gas wells. Renewable Energy, 41,80–85.

Cheng, W. L., Li, T. T., Nian, Y. L., & Wang, C. L. (2013). *Studies on geothermal power generation using abandoned oil wells*. Energy, 59, 248–254.

Cheng, W. L., Li, T. T., Nian, Y. L., & Xie, K., (2014). *Evaluation of working fluids for geothermal power generation from abandoned oil wells*. Applied Energy, 118, 238-245

Davis, A. P., & Michaelides, E. E. (2009). *Geothermal power production from abandoned oil wells*. Energy, 34, 866–872.

Templeton, J. D., Ghoreishi-Madiseh, S. A., Hassani, F., & Al-Khawaja, M. J. (2014). *Abandoned petroleum wells as sustainable sources of geothermal energy*. Energy, 70, 366–373.

Wei, D., Lu, X., Lu, Z., & Gu, J. (2007). *Performance analysis and optimization of organic Rankine cycle (ORC) for waste heat recovery*. Energy Conversion and Management, 48, 1113–1119.

SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

SCCER-SoE Annual Conference 2017

In cooperation with the CTI
Energy
Swiss Competence Centers for Energy Research
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Commission for Technology and Innovation CTI

Two pathways of SiO_2 scaling inside a high-enthalpy geothermal power plant

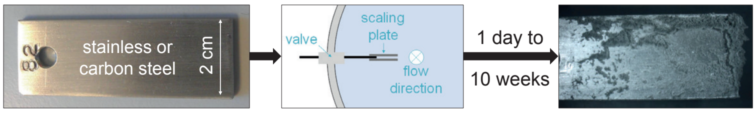
DB van den Heuvel[1,2], E Gunnlaugsson[3], I Gunnarsson[3], LW Diamond[1], LG Benning[2,4]

[1]Institut für Geologie, Universität Bern, [2]School of Earth and Environment, University of Leeds, [3]Reykjavik Energy, [4]Interface Geochemistry, GFZ Potsdam

1. Background

Precipitation (or scaling) of amorphous silica (SiO_2) is one of the biggest issues in high-enthalpy geothermal power plants worldwide, strongly reducing the amount of energy produced. While the precipitation in laboratory experiments is relatively well understood[1,2], the findings cannot be transferred directly to processes occurring inside geothermal pipelines due to the more complex fluid compositions, higher flow rates and rapid changes in physico-chemical conditions (e.g. cooling in the heat exchanger). However, a better understanding of SiO_2 precipitation inside geothermal power plants is needed to develop more successful mitigation approaches in the future.

2. Approach - Hellisheiði power plant (SW-Iceland)[3]

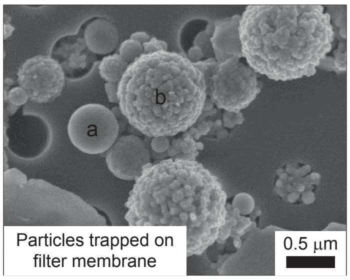


Fluid: Temperature & flow rate + Chemistry (ICP, IC)
Precipitates: Composition (XRD, EDS) + Scale microtexture (binocular, SEM, TEM)
Rates (Δthickness of precipitates and m(SiO_2) deposited)

3. Fluid chemistry

Temperature: 60 – 120 °C Flow rate: 220 – 430 L/s
Salinity: 0.9 – 2.6 %

Silica in the fluid
Dissolved SiO_2: 550 – 800 mg/L
(thereof monomeric silica: 75 – 85 %)
Particulate SiO_2: 0.2 to 0.3 mg/L (< 0.03 % of $SiO_{2(tot)}$)



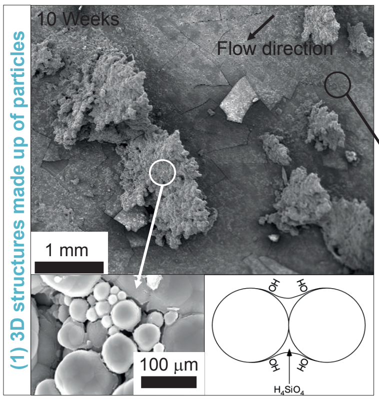
Particles trapped on filter membrane

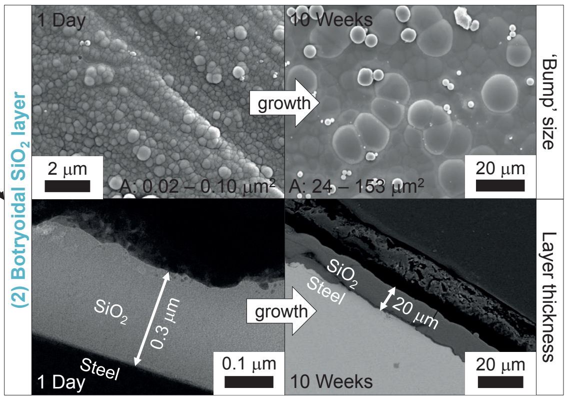
(a) Smooth SiO_2 microspheres

(b) Aggregates consisting of numerous smaller particles

4. Description of precipitates

Composition: amorphous SiO_2 containing Na, Cl, S, Al, Fe etc. (quantification currently underway)





Particle growth
- High c($SiO_{2\,(aq)}$)
- Elevated temperature
- Alkaline pH

Particle deposition
- Large particle size
- Hydrodynamics[4]

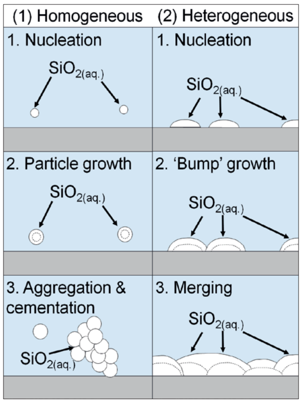
Layer nucleation
- Surface roughness[5]

Layer growth
- High c($SiO_{2\,(aq)}$)
- Elevated temperature
- Alkaline pH

CONTROLLING FACTORS

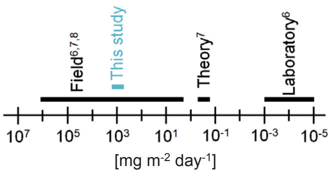
6. Precipitation mechanism and rates

Two types of precipitates occurring within the Hellisheiði power plant:



→ Two different mechanisms of precipitation (homogeneous vs. heterogeneous nucleation)

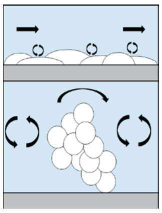
→ Different precipitation rates*



* Precipitation rates could only be quantified for the heterogeneous pathway in this study but observations show that the homogeneous pathway is faster

7. Implications for geothermal energy production

- To mitigate SiO_2 scaling completely, both pathways need to be inhibited/slowed down ⇨ development of novel additives
- Different textures affect hydrodynamics differently: 3D structures = turbulent flow
- Universal process? ⇨ more *in-situ* studies



8. Effect of salinity?

High salinity enhances precipitation via homogeneous pathway (aides aggregation of particles)
- Faster scaling rates (up to $8.5 \cdot 10^5$ mg m^{-2} day^{-1} at 5 % salinity)
- Turbulent flow ⇨ friction ⇨ reduced fow rate ⇨ less energy

⇒ High-enthalpy systems in sedimentary basins (e.g. the Molasse Basin) are at greater risk of extensive and detrimental SiO_2 scaling

Acknowledgement
The authors are grateful to the staff at Hellisheiði involved in the sampling and analyses conducted as part of this study and the following people for technical support: R. Walshaw (SEM) and L. Neave (XRD), both University of Leeds, R. Wirth (TEM) and A. Schreiber (FIB), both GFZ Potsdam and A. Berger (SEM), Universität Bern. This research was made possible by a Marie Curie grant from the European Commission (MINSC ITN 290040) and the 2014 IGA PhD Student Research Grant.

References:
[1] Icopini et al., *GCA*. **2005**, 69. [2] Tobler et al., *GCA*. **2009**, 73. [3] Meier (now van den Heuvel) et al., *Min. Mag.* **2014**, 78. [4] Hawkins et al., *Europhys. Let.* **2013**, 102. [5] van den Heuvel et al., in prep. for *Geothermica*. [6] Carroll et al., *GCA*. **1998**, 62. [7] Tobler et al., *Geobiol.* **2008**, 6. [8] Okazaki et al., *Sci. Rep.* **2017**, 7. [8] Rimstidt & Barnes, *GCA*. **1980**, 44.

The results presented here are in the final stages of preparation for submission to *Chemical Geology* as van den Heuvel et al., Geothermal pipelines as a well-constrained system for the study of amorphous silica precipitation mechanisms and rates.