

AN EXPERIMENTAL MEASUREMENT OF THE ADSORPTION OF SUPER-HEATED STEAM

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1. Introduction

The adsorption of liquid water in a vapour-dominated geothermal reservoir is one way the rocks hold fluids. The presence of this adsorbed water must be taken into account in the evaluation of the reservoir capacity.

A great number of papers have been published in the last ten years on this matter (see for instance [Hornbrook, 1994], and [Economides, 1985]); at Stanford University a big effort was carried out in experimental measurements of the adsorption/desorption from reservoir samples (see [Shang, 1994¹]).

In Italy we have a new geothermal field not exploited yet, in the Monteverdi region (southern border of Larderello), where 16 productive wells were found, supplying two 20 MW geothermal units. All the wells produce superheated steam.

The effect of adsorbed water was simulated, and the results will be presented in WGC 95 [Bertani, 1995].

2. Adsorption Simulation

2.1. Grid geometry and thermodynamic conditions

A mathematical model of the field was developed in order to have a preliminary field evaluation, using the STAR [Pritchett 1992].

The reservoir area is a roughly rectangular shape of 4x8 km, and the reservoir elevation is from -1000 to -3500 m a.s.l.

The grid used for the simulation is rectangular, with all the cells 500x500 meters in each horizontal (XY) plane.

The number of cells is 8x15x12, covering a volume of 4000x7500x2500 m³. The vertical thickness of the reservoir is from -3500 to -1000

m a.s.l. The grid orientation is north-west-south-east, as shown in Figure 1.

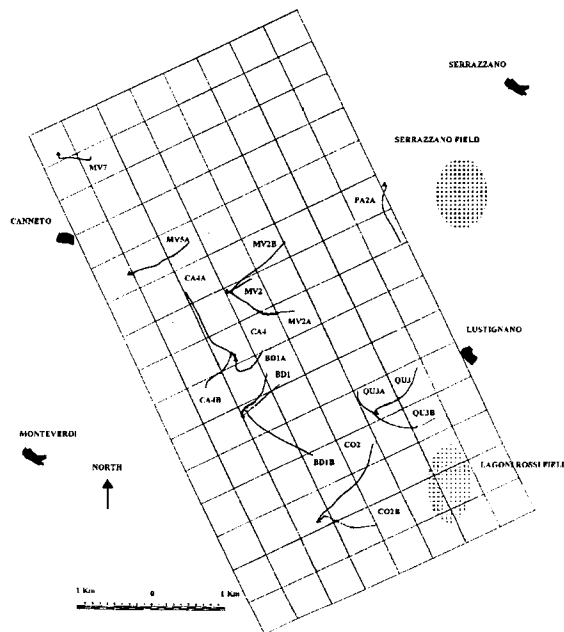


Figure 1: Monteverdi zone with the grid orientation.

The vertical (Z) cell distribution is irregular starting from 500 (at the bottom) to 100 meters (at the top).

Temperature and pressure indicate superheated conditions; the maximum degree of superheat is 70°C (7.5 MPa and 360°C). The initial temperature distribution was based upon extrapolated values taken *ad hoc* during drilling; the temperature distribution at -2500 has a maximum to the south-east (360°C) and a

minimum to the north-west (300°C), as shown in the contour plot given in Figure 2.

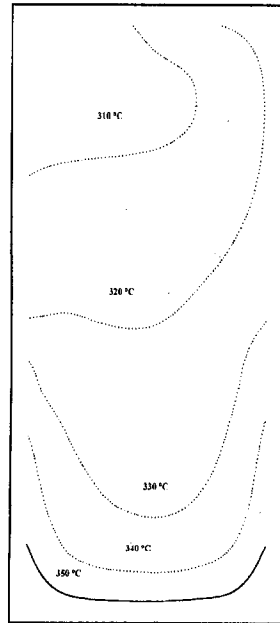


Figure 2: Isotherms at -2500 m a.s.l.

2.2. Results of Simulation

Available experimental data show that the amount of adsorbed water depends on the pressure, temperature and rock properties. Only a small fraction of the pore volume can be occupied by the adsorbed film, but the overall effect on the fluid density can be significant: for example, at 350°C and 7 MPa the steam density is 28 kg/m³; we have, with 10% of the pore volume filled with liquid water, a change of the effective steam/water mixture density to 85 kg/m³, with an increment of 200% in fluid storage.

We can define a global reservoir value of the amount of adsorbed liquid water per kg of rock (called ADS in the present paper).

We simulated the natural state with different values of ADS, with all the other rock parameters unchanged.

The results of the exploitation are illustrated in Figure 3. The average electrical power for 20 years roughly increases from 15 MW (ADS=0) to 35 MW in the two ADS runs.

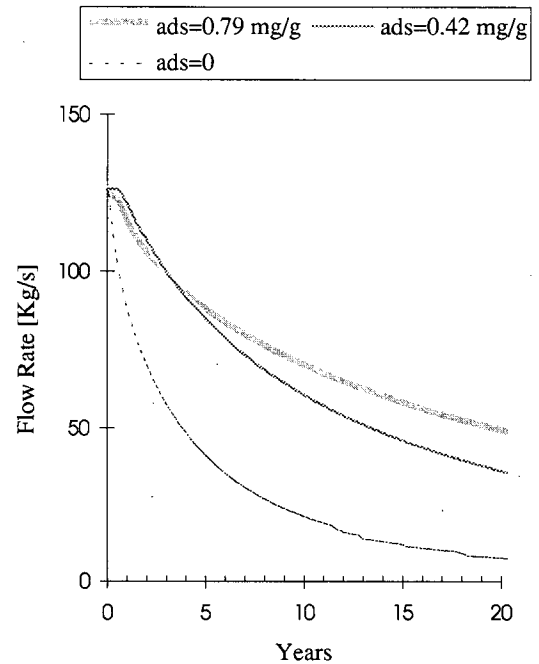


Figure 3: Simulated exploitation for different adsorption values.

The important effect of the value of ADS on the total electrical energy is evident. In any case, with the lowest value (ADS=0.42), we can exploit the reservoir for twenty years with adsorbed water still stored in the pore volume. For this reason, there is only a small difference between the two ADS values over practical industrial exploitation time scales.

On the other hand, in the two ADS cases, it is possible to exploit the reservoir with a different number of wells: it will give a greater difference of extracted mass in the same time.

3. Experimental measurements

Unfortunately, there is a lack of measurements of the adsorption parameters in the high temperature region, where our reservoir is located.

The experimental data available for Monteverdi are shown in Figure 4 from [Shang, 1994¹].

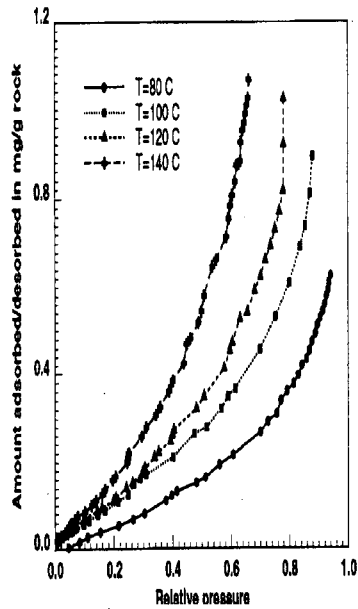


Figure 4: Stanford measurements on Monteverdi sample.

For this reason, we have planned an experiment, on the basis of the Stanford ones, in order to measure the Desorption versus Pressure curve with the Monteverdi sample.

3.1. Apparatus

The experimental apparatus is shown in Figure 5.

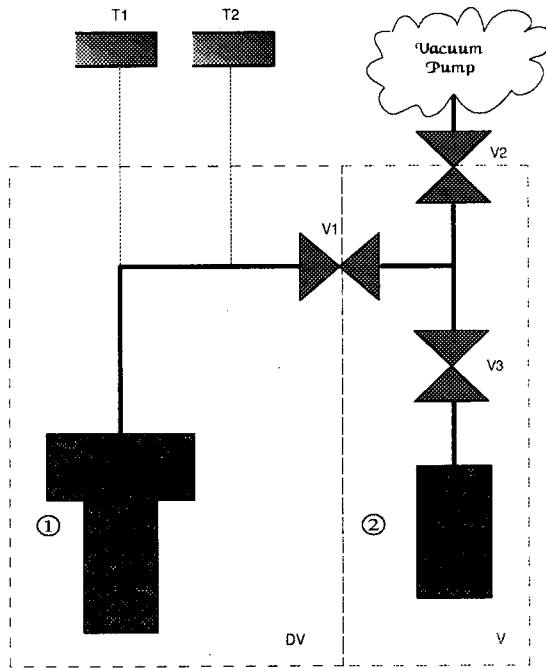


Figure 5: Experimental apparatus.

All is inside an oven, fully insulated. Data on pressure and temperature are recorded by a Data Logger.

The maximum reachable temperature is 250 °C, limited by the valves and cables; the pressure/temperature transducer is certified only below 230 °C. The main operating parameters are collected in the following table:

Item	Description
Sample Holder (1)	This is the container of the cutting; the mass of the rock sample is 300 g. The Dead Volume (DV) is 1.50E-4 m ³ .
Expansion Volume (2)	The total volume of the expansion chamber (V), with piping and valves is 1.145E-4 m ³ .
Valve V1	This is the valve which separates the Dead Volume (DV) and the expansion one (V). It is opened for expansion, with valve V2 closed.
Valve V2	This is used after each expansion step, with V1 closed, in order to evacuate the volume (V).
Valve V3	Not used in operation.
Transducer T1	This is a thermoresistance (class A IEC 751: ±0.5°C at 200°C), giving the internal sample temperature: it is inside the rock.
Transducer T2	This carries Pressure and Temperature coupled signals, which are used for the experimental measurement; the precision is ±0.18% span (2.5 Mpa), i.e. 4.5 KPa.

The work of [Shang, 1994²] has demonstrated the equivalence of measurement of core samples or cutting, as shown in Figure 6.

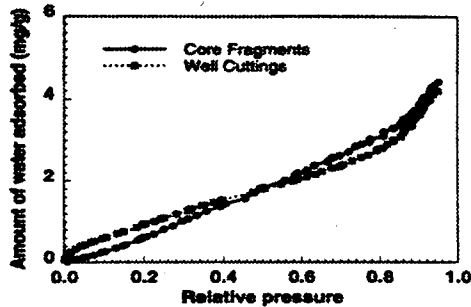


Figure 6: Comparison between core and cuttings.

Using cuttings the experimental procedure is speeded up, due to the smaller equilibrium times.

3.2. Experimental procedure

Preliminary, the Dead Volume was measured using helium expansion between DV and the volume V; the Dead Volume is the free volume in the core holder, including tubing and pore volume, excluding only the rock. First of all, the sample is fully water saturated; and afterwards a vacuum is made inside the circuit. Then, the temperature rises until the desired value is reached (for instance 180 °C); and the pressure is monitored, with venting of the excess water. When an equilibrium is reached at super-heated conditions, approximately after 24 hours, the valve V2 is opened and the vapour fills the second part of the apparatus; the pressure will decrease as in Figure 7.

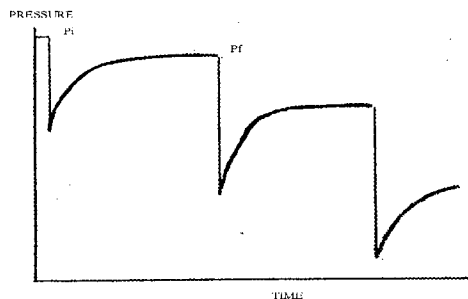


Figure 7: Pressure transient (theoretical).

The steady state pressure (after 2-3 hours) has higher values than the isothermal expansion at a constant number of moles, because of the desorbed water from the sample.

From the pressure difference between the iso-moles value and the actual one, it is possible to determine the mass (in mg) of desorbed water per gram of rock, at the final relative pressure, from the following simple equations:

- M_i = Initial mass of steam in the Dead Volume;
- P_i = Initial pressure of steam in the Dead Volume (measured);
- P_f = Final pressure of steam after expansion (measured);
- P_f^0 = Final pressure at a constant number of moles (no desorbed water);
- DELTA is the amount of desorbed moles of water from the rock sample.

$$M_i = \frac{P_i * DV}{Z * R * T}$$

$$P_f^0 = \frac{Z * M_i * R * T}{(DV + V)}$$

$$P_f = P_f^0 + \frac{Z * R * T * DELTA}{(DV + V)}$$

The final ratio ADS (in mg of water per grams of rock) is given by

$$A D S = \frac{D E L T A * 18}{R o c k - M a s s}$$

Due to the volumes and the precision of the pressure transducer, the minimum desorbed water which it is possible to measure is roughly 0.05 mg/g.

4. Conclusion

The apparatus for the ENEL desorption experiment is able to measure the isotherms for rock samples of relative big size (~300 grams), from 140°C to 240°C; our goal is the measurement at 180°C, 200°C and 220°C of different samples, in order to estimate an average reservoir desorption curve.

Comparison with Geyser samples are also in schedule.

5. References

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