Ferrara , 21, 22, 23 Settembre 2010 - Congresso:
Risorse geotermiche di media e bassa temperatura in Italia. Potenziale, Prospettive di mercato, Azioni
Sessione POSTER

Organizzazione — con la collaborazione di

PROFILI wellbore flow simulator : from geothermal wells to GHG and acid gas injection wells

Alfredo Battistelli

Saipem SpA, RISAMB Dept., Via Toniolo 1, 61032 Fano (PU), Italy

Modeling of flow in geothermal wells

The modeling of flow in geothermal production wells is conventionally used in reservoir and production engineering activities such as: support to well completion design; interpretation of downhole flowing P/T measurements; evaluation of well deliverability as a consequence of changes in bottomhole P&T, fluid enthalpy and composition, or diameter reduction and casing roughness increase due to solids precipitation.

Modeling of flow in geothermal wells requires the simultaneous solution of mass, momentum, and energy balance equations for the flow of a fluid mixture containing, in addition to water, salts and non-condensable gases (NCG). Fluid conditions can be single-phase liquid and two-phase in wells producing from water-dominated reservoirs, and single-gas (dry steam) in wells producing from vapor-dominated reservoirs.

Several numerical wellbore simulators have been developed in the last decades for basic research purposes as well as for industrial applications and some of them are available as public domain or commercial codes.

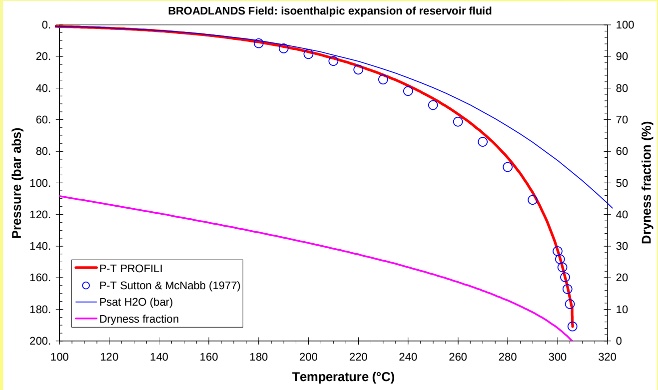

***Fig. 1. - PROFILI validation**: isenthalpic expansion of CO_2-rich reservoir fluid, Broadlands Field (Sutton and McNabb, 1977).*

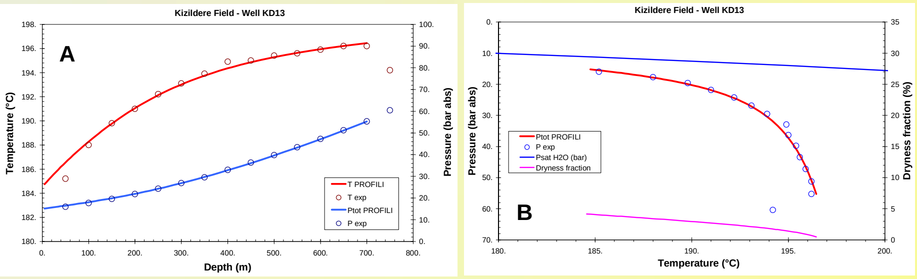

***Fig. 3 – PROFILI validation**: (**A**) reproduction of P&T flowing profiles recorded in well KD13, Kizildere Field, Turkey (Russel, 1975); (**B**) reproduction of P-T path followed by the CO_2-rich produced fluid compared with the saturation pressure of pure water.*

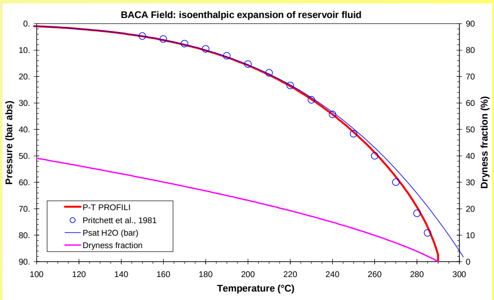

***Fig. 2 – PROFILI validation**: isenthalpic expansion of CO_2-rich reservoir fluid, Baca Field (Pritchett et al., 1981).*

PROFILI numerical wellbore simulator

Aquater SpA, now incorporated into Saipem SpA, developed for its geothermal E&P activities a steady-state numerical wellbore simulator for vertical production wells discharging two-phase mixtures of sodium-chloride dominated brines with CO_2 to represent non-condensable gases. The code, called **PROFILI**, was applied to model discharge conditions in both high and low enthalpy wells, and in the presence of high contents of salt and CO_2.

The present **PROFILI** version can be applied to simulate the steady-state flow of ternary mixtures of water, NaCl and one NCG (such as CO_2, CH_4, or N_2) for geothermal well applications with the following capabilities:

- two-phase flashing wells or dry-steam wells;
- production or injection conditions in vertical and directional wells;
- variable diameter completions and casing surface roughness;
- analytical computation of heat exchange between wellbore and surrounding rock formations;
- calculation starting from wellhead or bottomhole.

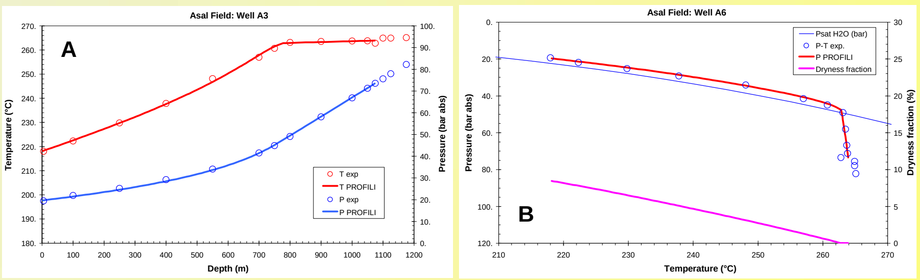

***Fig. 4 - PROFILI validation**: (**A**) reproduction of P&T flowing profiles recorded in well A3, Asal Field, Djibouti (Battistelli et al., 1992); (**B**) reproduction of P-T path followed by the NaCl-rich produced fluid compared with the saturation pressure of pure water.*

PROFILI has been validated by comparison with published thermodynamic results computed with other computer programs (**Fig. 1** and **2**) and reproducing published (**Fig. 3**) flowing P&T measurements in geothermal wells as well as downhole measurements performed by Aquater SpA within its geothermal E&P activities (**Fig. 4**). Simultaneous reproduction of both P and T logs is always performed to honour the thermodynamics of produced fluid mixtures. This allows to better evaluate the actual fluid composition and production enthalpy. High contents of dissolved solids (**Fig. 5A**) or non-condensable gases (**Fig. 5B**), responsible for the deviations to pure water phase behaviour, can have a remarkable effect on wellbore discharge characteristics. PROFILI can be used to simulate the output curve of a geothermal well by modeling wellbore flow as a function of discharge rate and BHP drawdown.

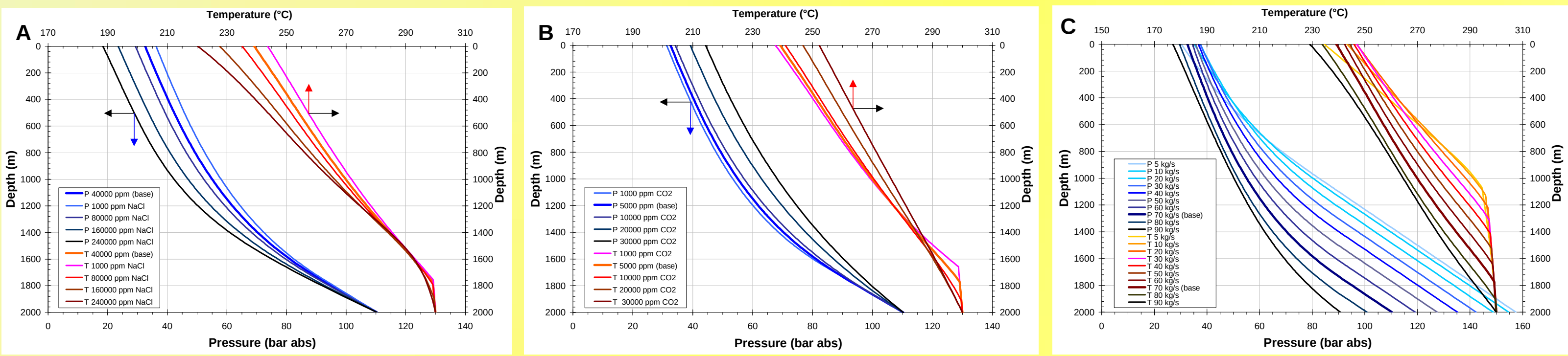

***Fig. 5 – A**: sensitivity on NaCl content; **B**: sensitivity on CO_2 content; **C**: sensitivity on production rate. SBHP=160 bar abs SBHT=300°C @ 2000 m. 9 5/8" production CSG @1500 m, roughness 5E-5 m, U=20 W/(m² °C); 8 ½" OH @ 2000 m, roughness 1.E-4 m. Production time 60 days. Static temperature profile: 20°C @ 0m, 260°C @ 1000 m, 300°C @ 2000 m. Base case: NaCl = 40000 ppm, CO_2 = 5000 ppm, rate W = 70 kg/s. BH flowing pressure is given by BHP = SBHP – 0.5 W – 0.003 W².*

EWASG EOS

The thermodynamic package employed for geothermal applications is an improved version of the **EWASG** EOS module (Battistelli et al., 1997) developed for the **TOUGH2** reservoir simulator (Pruess et al., 1999). EWASG can handle phase equilibria and fluid properties calculations up to **350°C** for H_2O-NaCl-CO_2 mixtures conventionally found in low and high enthalpy geothermal reservoirs. The EOS module can also handle CH_4 or N_2, instead of CO_2, as they can predominate in brines produced from aquifers present in sedimentary basins, such as the Po Plain or the Pannonian Basin.

PROFILI-TMGAS version

PROFILI can also model the single-phase flow of non-aqueous mixtures in gaseous, condensed or supercritical conditions, containing water, inorganic gases as well as hydrocarbons for applications related to natural gas production wells, gas storage wells, GHG and acid gas injection wells. In this case PROFILI uses the **TMGAS** EOS module correlations (Battistelli and Marcolini, 2009) developed for the TOUGH2 reservoir simulator, able to handle non aqueous fluid mixtures up to approximately **260°C** and **100 MPa**.

PROFILI plus **TMGAS** EOS can be used to model the injection into suitable permeable formations of NCG mixtures separated from produced geothermal steam,

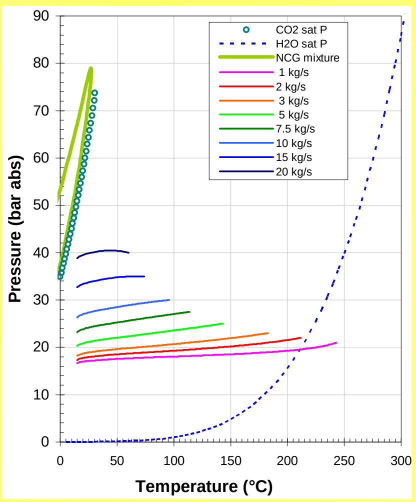

***Fig. 6 –** Phase envelope of NCG mixture and P-T path of injected fluid vs injection rate. The NCG mixture is in vapor and gas conditions.*

CO_2	H_2S	CH_4	N_2
91.0	3.5	3.5	2.0

***Tab. 1 –** Composition (% by volume) of injected NCG mixture.*

CO_2 injection in a saline aquifer is under consideration at Hellisheidi Field, Iceland (Aradottir et al., 2009) to reduce the environmental impact of geothermal exploitation. NCG reinjection could also be considered in mature vapor-dominated reservoirs where environmental concerns are limiting further field development. The composition of a typical NCG mixture separated from the steam produced from a vapor-dominated field is shown in **Tab. 1**. NCG injection at constant WHT of 15°C and at increasing rates is simulated using **PROFILI** with **TMGAS** EOS, assuming a 2000 m deep well completed with a 7" CSG. **Fig. 6** shows the phase envelope of NCG mixture compared to the saturation pressure of CO_2 and water. The static formation temperature profile is shown in **Fig. 7**, together with the simulated injection temperature profiles. Flowing pressure profiles are shown in **Fig. 8**. Initial SBHP is 20 bar abs @ 2000 m, typical of a depleted zone of a vapor-dominated reservoir. It is assumed that flowing BHP build-up is 1 bar/(kg/s). **Fig. 6** shows that the NCG mixture is always in gas conditions along the wellbore. While flowing temperature decreases strongly as the injection rate is increased, WHP requirements are limited by the increase of average fluid density.

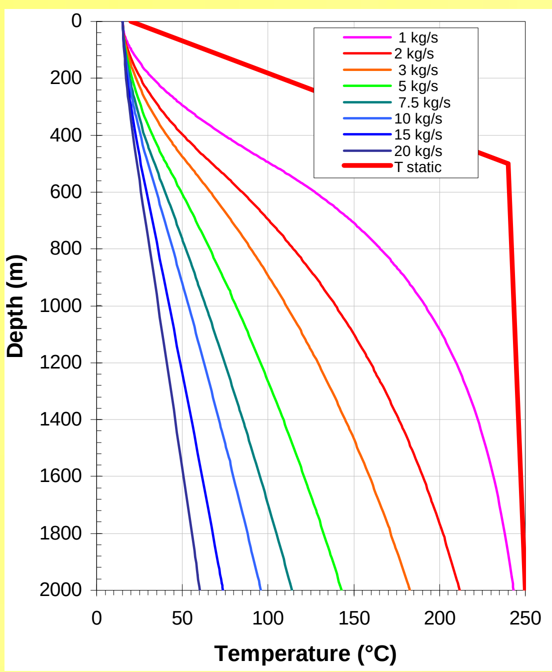

***Fig. 7 – PROFILI - TMGAS**: flowing temperature profiles at different NCG injection rates. The effects of heat exchange with surrounding rock formation are strongly reduced at high injection rates. The overall heat transfer coefficient of well completion is U = 13 W/(m² °C).*

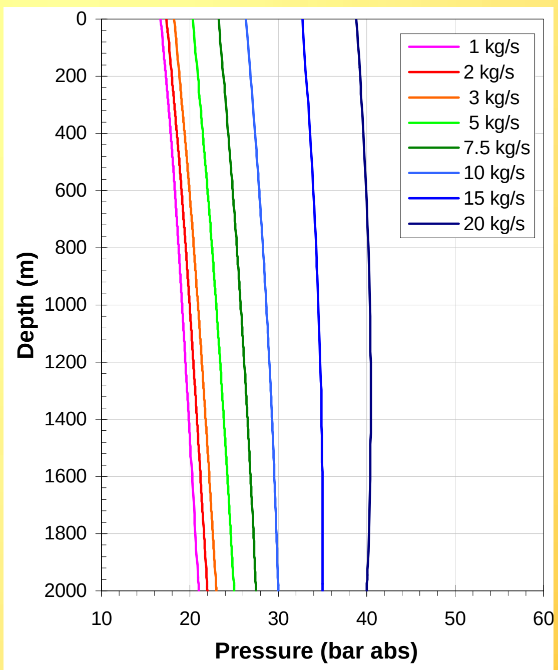

***Fig. 8 - PROFILI - TMGAS**: flowing pressure profiles at different NCG injection rates. The hydrostatic pressure gradient is balanced by friction losses: the resulting overall pressure gradient is rather low.*