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Design of deep geothermal wells

Progettazione di pozzi geotermici profondi

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This work aims to provide a flavour of some of the geothermal drilling activities, with the main focus on the well design and completion. Some related topics are also shortly reminded, such mud selection, cementing, blowout preventer.

Despite the overall technological developments and the new findings on exploration subjects, the road to endogenous heat resources for electricity production is driven by the same basic methods which have been developed for the very begin of geothermal exploitation: geothermal wells.

Indeed, drilling a geothermal well is the most common method (actually the only one…) to exploit geothermal resources for energy production purposes. Moreover, drilling technologies are usually developed in oil industry, and then transferred and adapted for the benefit of geothermal industry. As results, geothermal drilling technology used to running after oil technology developments so far. Tailor made drilling technologies for geothermal applications are available since recent years, thanks to EU grants (Van Wees et al. 2015). During the last decades, "geothermal advanced countries" (mainly New Zealand and USA) drove drilling technologies on technology developments (Grant and Bixley 2011; Di Pippo 2012a). Of course, drilling technologies are still growing and improving, especially on safety, knowledge, cost analysis, materials.

From a drilling perspective, standard water wells differ too much from geothermal and oil methodologies. This difference is quite clear for a well design viewpoints. Indeed, the water wells targets are usually shallower than the geothermal ones; water wells and geothermal wells mainly diverge for the temperature, pressure and hydrochemistry conditions, though.

Well design and well completion are driven by data availability and the target achievements need a fully team work. For the most relevant wells - especially in the oil industry – the completion engineer has the key role among other professional experts, such drilling engineers, well loggers, reservoir engineers, geophysicists, mud loggers and engineers, geologists, etc. (Bellarby 2009).

In the geothermal industry, well design and completion typically involve a smaller group of experts, but team work attitude remains an irreplaceable approach for the accomplishments of the expected goals.

Most geothermal wells have 2 to 5 cemented casing strings, whit the thumb rule that deeper wells need more strings (Thorhallsson 2008); indeed deeper and hotter reservoirs usually may require larger number of casing strings, in order to safely penetrate the high temperature reservoirs (Thórhallsson et al. 2014)

The main purpose of the casings is:

- To hold up the open hole;
- To seal out the aquifers and to prevent fluid migration among different formations;
- To allow control of blowouts and to anchor the wellhead;
- To provide a conduit for the well production.

Therefore, the basic steps in the well design are to (Thorhallsson 2008):

- Determine the number of casing strings required, the diameters and lengths of each casing strings, as the sketch of fig. 1 suggests.
- Calculate the collapse and burst and determine the required casing thickness.

The main reason for the large number of casing strings for high temperature wells is to support the hole and especially to provide safety in controlling blowouts (fig. 1).

The formation permeability and the rock hardness also comes into consideration when deciding on the casing depths.

According to fig. 1, large-diameter "conductor casing" is generally quite shallow and it is run to depth in order to protect shallow formations from drilling fluids contamination; moreover, it supports washouts involving unconsolidated soils and sediments. "Surface casing" has a smaller diameter and it maintains the borehole integrity. The main purpose of the surface casing is to prevent contamination of shallow groundwater from brines, deeper (salty) groundwater and drilling fluids. The "intermediate casing" is not always run to depth, if the other casing strings can safely reach the reservoir section; intermediate casing isolates high pressured formation, fractured and lost circulation zones; consequently, intermediate casing provides well control and prevent environmental issues. Eventually multiple intermediate casings may be required to reach the target producing zone. The "anchor casing" is run in deeper wells where kick tolerance or troublesome formations make it unsafe or undesirable to drill from the surface casing all the way to the production casing setting depth in the hole section (Moumin 2014).

The "production casing" (or liner) is the last and smallest tubular element in the well. Production casing has to consider the minimum target temperature by reaching at least that deep into the reservoir. It isolates the zones above and within the production zone and withstands all of the anticipated loads

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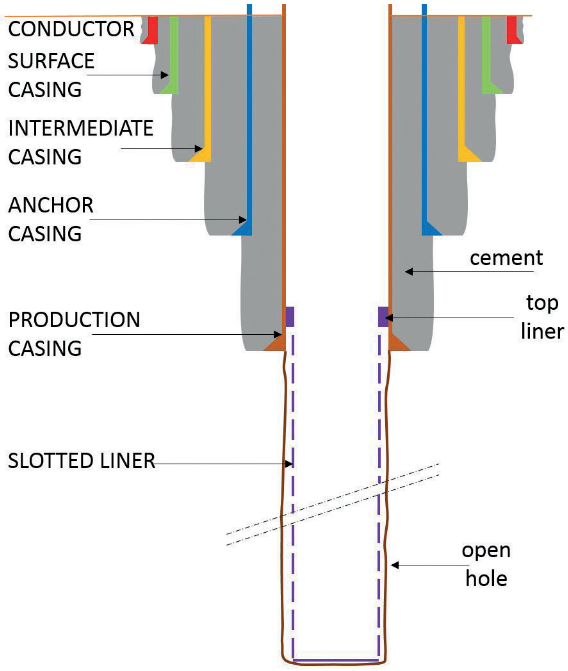

Fig.1: general representative geothermal well design. The intermediate casing could be omitted in some cases. Diameters depend on many factors, such geology, geothermal conditions, total depth, reservoir permeability, rig power, etc.

Fig.1: schema generale di un pozzo geotermico. L'*intermediate casing* potrebbe essere omesso in qualche caso. I diametri dipendono da molti fattori, quali la geologia, le condizioni geotermiche, profondità totale, permeabilità del reservoir, dimensioni dell'impianto di perforazione, ecc.

throughout the well's life. The open hole covers at least the detected reservoirs and it is supported by a slotted liner or screen. This allows any geothermal fluid to enter the well (Finger and Blankenship 2010).

To define the minimum casing depth for each casing string in a high-temperature well the temperature and pressure vs. depth should be known for the well to be drilled. The "worst possible case" for casing design (e.g. in a new area where actual information is not available) is the Boiling Point Depth curve (BPD) (Thorhallsson 2008), as described in fig. 2.

Indeed, most high enthalpy resources contain two phases (either vapour or water dominated), with temperature and pressure conditions controlled by saturated steam / water relationship BPD. Just for design purposes, where downhole pressures and temperatures are not known, BPD conditions are assumed from ground level as indicated in fig. 2 (Dumas et al. 2013).

Depths of all cemented casing strings and liners are determined such that the casings can safely contain all well conditions resulting from surface operations and from the characteristics of the formations and fluids encountered as drilling proceeds. Casing shoe depths are calculated by analysis of data from adjacent wells which will include rock characteristics, temperatures, fluid types and compositions and pressures. These wells could provide additional data regarding the formation fracture gradient.

Coupled to the well design program, also the mud program must to be planned in order to safely couple each casing string to the formation parameters. Indeed, in order to manage the formation pressure and stabilize the well, the mud pressure must be controlled in a small pressure window between the pore pressure and the formation pressure / fracture gradient of the rock (Vollmar et al. 2013).

As fig. 1 highlights, each casing string must to be well cemented. Unlike oil wells, casings in geothermal wells are all usually run back to the surface and are accordingly fully cemented back to the surface as well. The high thermal stresses imposed on the casings demand uniform cementation over the full casing length, such that the stress is distributed over the length of the casing as uniformly as is possible and such that stress concentrations are avoided (Antics et al. 2010).

The objective of any casing cementing programme is to ensure that the total length of annulus (both casing to open hole annulus, and casing to casing annulus) is completely filled with sound cement that can withstand long term exposure to geothermal fluids and temperatures (Hole 2008).

In order to obtain a good cement bond, the annulus has to be filled to the surface by well, based on wellbore conditions. There has to be an excellent bond between casing and cement and between the cement and the formation. In order to check the cement job quality, "cement log bonds" are nowadays performed in the well. Throughout this geophysical method, acoustic logs provide the primary means for evaluating the mechanical integrity and quality of the cement bond (Bett 2011).

The biggest risks in the geothermal well drilling is the blowout one. This occurs when an unexpected, high-pressure permeable zone is drilled. In order to safely drill, the use of blowout preventers (BOP) is standard geothermal practice nowadays. In the BOP, a series of fast-acting ram-type valves are fixed to the surface casing, and through which the drill pipe rotates. In case of a so-called "steam kick" from the well,

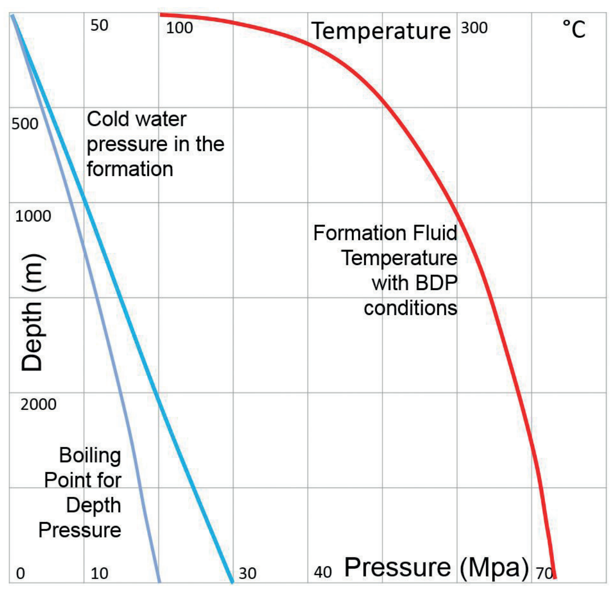

Fig. 2: Downhole Pressure and Temperature condition according to the Boiling Point for Depth Pressure

Fig. 2: Definizione della Temperatura e della "*Downhole Pressure*" seconda del "*Boiling Point for Depth Pressure*".

these valves are slammed tight around the drill string, effectively closing off the well (Di Pippo 2012b).

Once the geothermal well is finalized (and cleaned), the well testing program begins. Usually, such program starts with discharging/pumping tests, since both rig and pumps are already on site and the overall costs may be minimized. Well testing program is very significant, since the interpretation of this kind of survey provides detailed data about well enthalpy and its commercial value (Cultrera 2016).

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