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Authors: Adele Manzella (CNR), Ruggero Bertani (EGP)

Co-operators:

Eugenio Trumpy (CNR)

Abstract:

This document, prepared in the frame of WP6, provides the second Fact Sheet of the DESCRAMBLE project, organized following the format of the first Fact Sheet delivered on October 2016. The Fact Sheet summarizes the main technical details of the projects and its results.

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FINAL PROJECT FACT SHEET
EUROPEAN UNION CO-FUNDED PROJECT

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Horizon 2020

GEOTHERMAL ENERGY

Project acronym:

DESCRAMBLE

Drilling in dEep, Super-CRitical AMBient of continentaL Europe

Authors:

A. Manzella, E. Trumpy, R. Bertani

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Coordinating entity: ENEL GREEN POWER (EGP)
Via Andrea Pisano 120 – 56122 Pisa - Italy
Coordinator: Dr. Ruggero Bertani
Tel.: 0039–0506185650 email: ruggero.bertani@enel.com

Project web site: http://www.descramble-h2020.eu

1. SUMMARY

The "**D**rilling in d**E**ep, **S**uper-**CR**itical **AMB**ient of continenta**L** **E**urope" (**DESCRAMBLE**) project has developed novel drilling technologies for a proof-of-concept test of reaching deep geothermal supercritical resources. In the project, ***the hottest well in the world in continental-crust condition has been safely drilled*** and demonstrated novel drilling techniques, the control of gas emissions and high temperature/pressure conditions from the deep depth. The project has also improved knowledge of deep chemical-physical conditions for predicting and controlling future drilling conditions. The test site has been an existing dry well in Larderello, Italy. In the area, available seismic survey data had highlighted an important deep seismic reflector named "K-horizon" culminating below the currently exploited, vapour-dominated, reservoirs and recognizable throughout southern Tuscany. The high impedance of this seismic marker, even resembling a bright-spot in some areas, was interpreted as due to magmatic/metamorphic fluids, possibly in super-critical conditions. The existing dry well, already drilled to a depth of 2.2 km and temperature of 350 °C, was deepened to about 2.9 km depth, reaching temperature of 507-517 °C, pressure of about 300 bar but no sign of fluids.

The productivity and efficiency of the project were ensured by the combination of industrial and research participation and by the recognized expertise of the consortium in geothermal R&D as well as oil and gas drilling, combining excellence in both sectors. DESCRAMBLE's results cover multiple aspects: drilling procedures, material, well control, mud logging, well testing, modelling, geochemical and geophysical surveys and monitoring, petrographic and petrophysical evaluations and very high temperature - pressure logging tool.

The activity was supported by internal information and dissemination activity, including knowledge exchange with developer of similar projects through conferences and meetings.

2. PROJECT SCOPE

DESCRAMBLE's scope has been the development of new drilling technologies and concepts for geothermal energy exploitation from deep and super-critical geothermal resources in continental geological condition in Europe and its testing. DESCRAMBLE's specific objectives were:

- Demonstrate safe drilling of a deep super-critical geothermal well.
- Reduce the technical and financial risks of drilling and exploiting deep geothermal wells by improving knowledge of the physical and chemical conditions in deep geothermal formations.
- Reduce pre-drill uncertainty in the exploration of deep geothermal wells by applying the latest seismic processing, imaging and interpretation technology for exploring the supercritical reservoir prior to drilling.
- Investigate the economic potential of exploiting chemicals and minerals by analysing fluid samples for valuable material

3. PROJECT TECHNICAL DESCRIPTION & IMPLEMENTATION

To achieve DESCRAMBLE's scope, the first and hottest drilling in the world in an intra-continental site at a middle-crustal level has been performed, testing and demonstrating novel drilling techniques to control gas emissions, the aggressive environment and the high temperature/pressure encountered at depth. Moreover, the project has improved knowledge of deep chemical-physical conditions for predicting and controlling critical drilling conditions by performing rock and fluid analyses and numerical physico-chemical simulation of the area.

The project has run 36 months (3 years), and was organized into two main sections: (1) Drilling in supercritical conditions, including drilling components, well materials, design and control; (2) Geo-Scientific activities for predicting and controlling critical conditions, by considers petrological, physical and chemical characterization, simulation and monitoring, including high temperature and pressure measurement tools.

4. RESULTS ACHIEVED

The project has achieved the following main outcomes:

- ***Drilling operations in extreme conditions*** were carried out ***safely*** and can be considered a significant success of the project. To achieve this result, innovative geothermal technologies, equipment and materials specifically designed for extreme temperature and pressure conditions and specific drilling procedures have been used, representing a significant learning opportunity for the geothermal drilling industry.
- ***Novel drilling modelling*** was developed, by modifying a simulation tool already available for the flow of drilling and formation fluids during drilling of oil and gas wells. Various simulations were carried out for the DESCRAMBLE superhot drilling conditions, to determine if the drilling crew could use the return flow to detect influx from the formation and boiling of the drilling fluid.
- ***Novel production modelling*** was developed, by modifying a commercial multiphase flow pipeline simulator initially developed for the oil and gas industry. The numerical simulation showed that providing (input) the likely pressures, temperatures and flow rates from a supercritical production well, surprisingly strong pressure and temperature fluctuations in the well during opening and closing of the choke valve should happen, and explained as due to the well's state being close to water's critical point.
- ***Superhot temperature (above 500 °C) and innovative temperature measurement tools*** at extremely high temperature conditions, for which commercial logging tools are not available. Temperatures were registered using various tools: a mechanical Kuster that measured data at full scale of the tool (> 504 °C); synthetic fluid inclusions registered a temperature range of 507-517°C; ***a novel logging tool*** (figure 1) that was built in order to measure P&T (pressure and temperature) with a minimum of 6 hours operation at temperature of 450°C (foreseen as bottom-hole temperature before drilling). According to the temperature data collected during the DESCRAMBLE project drilling, the temperature profile shows a sudden increase of the thermal gradient at the bottom hole. The data are not sufficient to determine the exact depth at which the thermal gradient variation occurs; nevertheless, the temperature log registered by the novel probe allows to locate it at about 2750m, in correspondence of the beginning of the seismic reflection zone. A leakoff pressure test measure ***pressure of about 300 bar***.

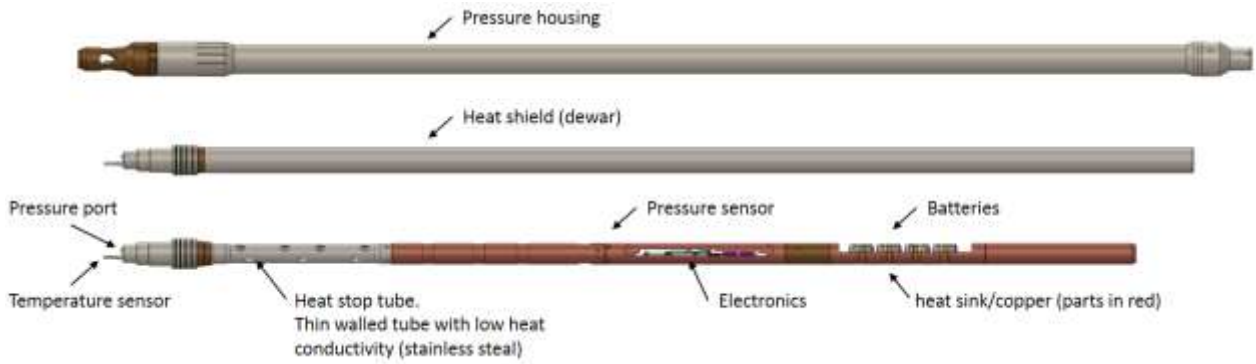

Figure 1 – (Top) The complete P&T logging tool with pressure housing. Temperature sensor and pressure port to the left (nose) and connection for the slickline wire to the right. (Middle) Pressure shield and nose protector removed. Picture show the nose of the tool and the heat shield. (Bottom) Heat shield removed. Picture show the inner parts of the tool. Electronics located in the middle of the tool.

- ***The supercritical reservoir characterization*** and a comprehensive understanding of the geological structure and physical conditions of the supercritical reservoir, which was needed in three stages of the project: a) before drilling in order for defining the model and constraining the framework in geothermal reservoir modelling and prediction; b) during the drilling phase to improve ahead drill prediction and operational steering; c) after drilling for assessing the agreement of prediction and findings and for deriving conclusions for a general guidance for identifying deep supercritical

conditions. To achieve these results, an investigation strategy was followed that included three main approaches: 1) conceptual; 2) indirect and 3) direct. The conceptual approach, from paleo-reservoirs outcropping in other areas of Tuscany, envisaged confined, dominantly magmatic, reservoirs in correspondence of seismic reflector named K-horizon. The indirect approach involved acquisition of new seismic data (VSP, Piggy back experiment) and use of existing three-dimensional (3D) and two-dimensional (2D) seismic data set to provide high-resolution seismic images of the K-horizon. The direct approach, i.e. the analyses of rock and fluid samples from the reservoir, could be not completed because the drilling stopped without encountering important amounts of fluid or lithological change. Numerous petrological and petrophysical analyses of rock samples, however, provided further insights of deep geological conditions.

- ***A refined reservoir modelling*** was achieved, and included: an advanced 3D geological modelling which embedded the interpretations of seismic data processing; transient thermal numerical modelling, which was carried out during the after the drilling and provided information of the evolution of the multi-phase magmatic intrusions of Larderello; advanced supercritical two-phase (water, steam), and multiple-phase (supercritical water, CO_2, NaCl) numerical modelling, which was calibrated with the thermodynamical results from drilling and represents a major step forward in the numerical modelling and the possibility to forecast the deep conditions for further deep drilling.

5. IMPACT

a. Replicability

DESCRAMBLE results opened a new segment of the geothermal market in other areas of Europe and abroad. Its novel high temperature logging tool was already requested for measurements in other sites.

b. Socio-economic

The DESCRAMBLE results ensure a short lead-time from research to innovation, by a) strengthening the European industrial technology base, thereby creating growth and jobs in Europe; b) demonstrating that super-critical wells can be safely drilled with acceptable financial risks.

c. Environmental

DESCRAMBLE has demonstrated an environmental-friendly way of drilling even in extreme conditions.

d. Market Transformation

By demonstrating safe drilling in supercritical conditions, DESCRAMBLE has paved the road to the deployment of deep geothermal resources with a cost reduction of 10-15% in comparison with a standard system at the same depth due to the 75% reduction of the drilling costs (reducing the number of wells needed), with additional possibility of a further 10% cost abatement due to the learning curve effect.
The use of the abundant and free heat as a by-product of the electricity production from a super-critical system could be an important add-on to the economic and environmental aspects.

6. ADDITIONAL INFORMATION

The activity on the well has been terminated at 2.9 km, concluding the data acquisition and leaving the well in safety condition through a temporary cement plug. The bottom home temperature exceeding 500°C was above the design value for the entire project, and it was impossible to cement the absorbing zone for further drilling in safety conditions. The drilling did not prove the existence of a reservoir and fluids. However, the thick pack of reflectors has been only partially investigated. From a technical point of view, the obtained results are a major outcome of the project, and according to the expected thermo-dynamical and geological forecasting down to further depth, the associated costs and risks from the gathered data do not justify additional drilling. However, a more detailed analysis is ongoing at Enel Green Power.