GEMex: Cooperation in Geothermal energy research Europe-Mexico for development of Enhanced Geothermal Systems and Superhot Geothermal Systems

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ABSTRACT

A focus of European research cooperation in the last years has been on developing concepts for the exploitation of unconventional geothermal resources such as Enhanced Geothermal Systems (EGS) or, more recently, Superhot Geothermal Systems (SHGS), including those with supercritical water. One such project addressing unconventional geothermal systems is the international cooperation between Europe and Mexico GEMex (Cooperation in Geothermal energy research Europe-Mexico for development of Enhanced Geothermal Systems and Superhot Geothermal Systems). The cooperation encompasses two partner projects, one funded within H2020 and one by the government of Mexico through the National Council of Science and Technology CONACyT. The projects are designed to explore two specific sites to develop concepts for their utilization as EGS and SHGS. The site for EGS development is the Acoculco crater, SHGS are investigated at Los Humeros, both in the eastern Trans-Mexican Volcanic Belt. Los Humeros is currently exploited with steam temperatures reaching up to 340°C. In some wells, temperatures higher than 380°C were inferred, but these are not currently used for energy conversion. The system feeding these super-hot wells is the target of GEMex investigations on SHGS. Acoculco is not currently exploited, but was the target of two 2km deep and 300°C hot wells that did not encounter any fluids, despite some surface manifestations indicating the presence of a hydrothermal resource.

The cooperation is supported through two partner projects, one funded by the government of Mexico and one through H2020, both called GEMex. Project start was in October 2016. The approach chosen for the cooperation on the two sites encompasses the entire development chain from resource assessment to detailed exploration, reservoir modelling and concepts for the exploitation of the unconventional geothermal resource. In this approach, the projects build strongly on previous and ongoing EU funded projects that addressed advanced and integrated exploration methods as well as drilling and developing superhot geothermal resources and advanced EGS concepts. The progress reached at both test sites will be reported at the EGC2019.

1. INTRODUCTION – STUDY SITES

1.1 Los Humeros

Los Humeros is a Quaternary volcanic complex with existing geothermal power plant facilities (Installed capacity 95.7MWe, from ~ 30 producing wells), developed and operated by the Comisión Federal de Electricidad (CFE). The focus within GEMex is on (1) an improved and comprehensive understanding of the location and characteristics of the deep superhot geothermal reservoir (SHGS), (2) its connection to the known conventional system based on a complementary, interdisciplinary approach of novel and established exploration and resource assessment methods, and (3) on concepts for the development of the superhot geothermal resource. Los Humeros is a system with reservoir temperatures > 380°C (> 2 km depth); however, due to the aggressive physicochemical characteristics of the geothermal fluids, a sustainable operation at superhot conditions has not yet been fully manageable for power generation.

1.2 Acoculco Caldera

Preliminary geological studies consider the Pliocene-Pleistocene Volcanic Complex of Acoculco a candidate for application of EGS technology. Focus within GEMex is on (1) an improved characterization of the geothermal system, (2) an evaluation if application of EGS technologies can hydraulically connect existing

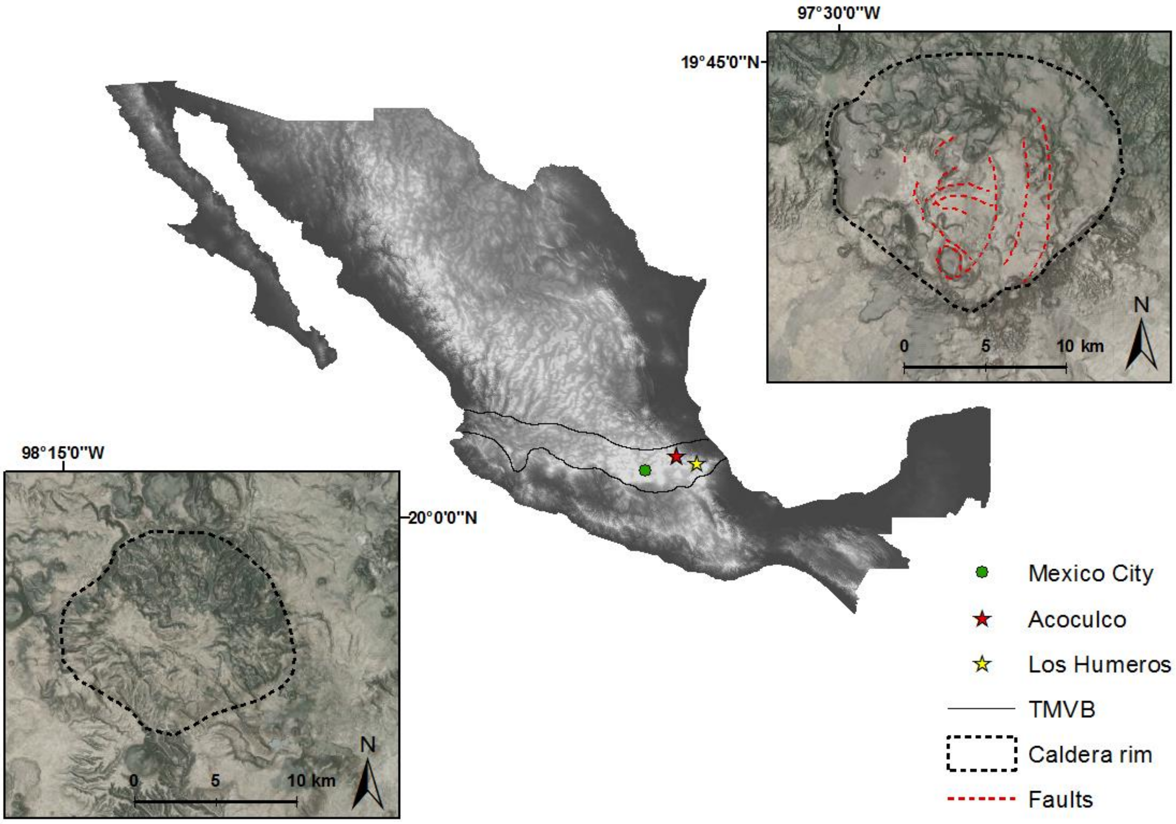

Figure 1: Location of test sites in Trans-Mexican Volcanic Belt

wells (~300°C at 2 km depth; hardly any fluids) to permeable and fluid bearing fracture zones nearby, and (3) defining the requirements for and designing of suitable stimulation procedures. The concept includes mitigation of induced seismicity and other potential environmental impacts.

2. PROJECT STRUCTURE

GEMex is structured into three major parts: Resource Assessment, Reservoir Characterization, and Concepts for site development.

I) The first part of the project on resource assessment at the two test sites focusses on understanding the tectonic evolution, the fracture distribution and hydrogeology of the respective region, and on predicting in-situ stresses and temperatures at depth.

II) Reservoir characterization is done using techniques and approaches developed at conventional geothermal sites, including novel geophysical and geological methods. The approach applied here builds on the methodology successfully tested within IMAGE, integrating geological and geophysical field data.

III) The models generated from the various old and new data will serve as basis for the final step in the project, the proposal of concepts for site development and for the utilization of the resource.

2.1 Regional Resource Models

GEMex is in the process of establishing a series of regional 3D models: 1) a 3D geological model, 2) a 3D temperature model, 3) a 3D hydrological model and 4) analogue models which rebuilt part of the features we observe in nature at the laboratory scale.

The complexity of the different datasets from geothermal exploration will be consolidated by data integration in cooperative 3D GeoModels (Calcagno, 2015). The primary objective is a comprehensive understanding of the tectonic and volcanological evolution of Acoculco and Los Humeros by deciphering the conditions and processes determining the development of these unconventional geothermal systems. All available geological data as well as geophysical constraints are used to develop models including volcanological, structural, thermal, physical and hydrological parameters from the geothermal system and beyond. These steps will help understand the resource and improve numerical reservoir models. Preliminary geological models are built using the initial database. New data collected during the project have been included to update the models continuously. An iterative "Knowledge and Data Sharing - Modeling - Validation" cycle has been established to keep the boundary conditions and input parameters for the integrated 3D models up to date. The 3D geological models are constructed with GeoModeller software using a potential field interpolation method combined with geological rules (Calcagno et al., 2008).

2.2 Tectonic Control on Fluid Flow

A major focus of the geological exploration efforts is on a comprehensive understanding of the tectonic control on fluid flow in the subsurface. Therefore, structural and kinematic data are not only collected from the active Acoculco and Los Humeros systems, but also from exhumed systems (e.g., Las Minas) nearby, in outcrops of the deep part of fossil geothermal reservoirs. The fieldwork activity is based on the classical approach of structural geology, and is enhanced through scanlines (e.g., Zucchi et al., 2017) and imaged fracture analyses, both at outcrop and thin section scale.

The exhumed systems at Las Minas are a hydrothermally mineralized mining area, and considered as the analogue of Los Humeros and Acoculco at depth and therefore representing the analogue deep roots of the active geothermal areas. By comparing the results from active and fossil systems, a conceptual model on the relationship between geological structures and fluid pathways has been derived.

Hydrological and geochemical data are collected from natural cold and warm springs and wells (including geothermal wells) within both geothermal systems, but also at the boundary and outside the system, taking into account altitude distribution, morphology and geostructural characteristics. Geochemical characterization of the fluids as well as temperature and pressure conditions present at depth are determined for the identification of the main recharge areas/origin of geothermal fluids. Furthermore, area-wide, multi-parameter soil gas analyses (e.g., CO2, 222Rn) focus on the spatial distribution of different gas concentrations/gas fluxes to identify and characterize permeable segments of major faults and fractures (Jolie et al., 2018). Airborne thermal imaging is applied in the same area to correlate results with soil gas data. The soil gas composition at Earth's surface is analyzed if it can be used as an indicator for the presence, dimension and characteristics of the deep superhot/supercritical geothermal system, analogous to the recent findings by Jolie et al. (2016), who established a link between soil gas, structural and fault stress data at the Bradys geothermal field in Nevada.

2.3 Detection of Deep Structures

The detection of deep structures in both Acoculco and Los Humeros geothermal systems is performed by applying innovative and optimized geophysical methods. The integration of all the applied techniques will allow the generation of comprehensive three-dimensional models to know the distribution of the main physical properties at depth and their relationship with the geothermal system. The combination of methods includes networks for passive seismic monitoring, electromagnetic measurements, both MT and TEM, as well as gravity measurements at both sites.

The electrical resistivity characterization through the magnetotelluric method (MT) and transient electromagnetics (TEM). This activity involves not only new data acquisition at both sites but also the generation of synthetic models to improve three-dimensional inversion schemes, implementation of novel methodologies in data processing as well as the comparison of obtained results with other models previously generated in similar geothermal fields.

Two local networks, especially installed by the GEMex consortia for a period of 12 months, record seismicity. The characterization of the seismicity in both geothermal systems includes techniques such as two-dimensional modeling of surface wave dispersion, three-dimensional modeling of seismic velocities, radial-anisotropy modeling and the determination of focal mechanisms. All these activities are performed to characterize active faulting, large discontinuities of the shallow crust and the fluid dynamics in the reservoirs. In Los Humeros 42 seismic stations have been deployed and will keep recording for one year. Another 15 seismometers have been installed in Acoculco. Prior to the deployment of the stations, synthetic model calculations helped to optimize the setup in the field. Seismic monitoring of the two fields will give important information on the tectonic movements/activity of the subsurface.

A full characterization of the heat flow in the Acoculco prospect is part of the planned work program. A map will be generated from information collected in a grid of shallow wells (50-100 m) drilled specifically for the project. This map will include anomalous heat transfer areas related to convective effects and presence of permeable conduits for the Acoculco prospect.

New gravity data have been acquired for both geothermal systems to generate three-dimensional models in order to infer structures related to permeability. Interpretation of gravity in the two areas will be a valuable addition to the knowledge on mapped tectonic structures.

Results from seismic and gravity measurements will be an important constraint in the modeling of the resistivity data, which helps in constructing conceptual models of the two areas. Subsequently, the generated models will be included in an integrated geophysical image based on MT, TEM, Seismic, Gravity, InSAR, GPS (i.e., joint inversion, geospectral modeling, structural coupling approach) in order to determine the variation of the physical subsurface parameters relevant for reservoir characterization.

2.4 Reservoir Characterization and Conceptual Models

Fluid flow in the Los Humeros geothermal field is dominated strongly by faults and fractures formed during tectonic and volcanic episodes. Therefore, one of the GEMex targets is the characterization of those faults and fractures that permit fluid flow. The two studies will be characterized with respect to rock and fluid properties and their variation with temperature and pressure.

Petrophysical and geomechanical properties of the rocks are tested by performing numerous laboratory experiments at ambient as well as simulated in situ p/T conditions on the outcrop analogues and reservoir rock samples. Understanding rock and fluid properties and their variation with temperature and pressure is also required for interpreting the subsurface model based on geophysical measurements on the surface and for the development of the two sites.

The results of the analysis of rock and fluid properties will be integrated with the geological and hydrological models and geophysical investigation of deep structures already obtained within the project in order to create static reservoir models. This parameterized models will be used in static and dynamic numerical simulations of fluid flow, heat transport and phase behavior before and during geothermal exploitation. Laboratory tests will be performed in order to simulate enhanced approaches and monitor induced seismicity.

The Acoculco geothermal field has been selected as a candidate for the application of EGS technologies. Previous studies define Acoculco as a hot, dry, and virtually impermeable system (Lorenzo Pulido et al., 2010). This characterization is based on two wells drilled until now and related literature. Since our field work has detected surface traces of a large normal fault close to the wells, the concept for EGS at Acoculco may focus on a hydraulic connection fault zone of the wells with the fault zone. The success of EGS depends largely on our ability to understand the fracture growth and connectivity of the fractures created. To this extent, we perform hydraulic fracturing experiments of rocks under controlled conditions at a scale sufficiently controllable in the laboratory but, at the same time, adequate for providing a reliable data set for verifying different numerical codes used for the layout of hydraulic stimulation operations. Experiments are performed on samples of granite and skarn collected from regions around Acoculco and believed to be representative of an optimal target formation for EGS in Acoculco.

2.5 Concepts for Reservoir Development and Utilization

GEMex will provide options to make a reliable use of the geothermal reservoirs at both locations possible. On the basis of previous experience in other H2020 projects and on the information acquired during our joint project approach in GEMex, concepts will be proposed for the development of a high temperature EGS at Acoculco and for the exploitation of the SHGS encountered at Los Humeros.

Concepts for the development and utilization of engineered geothermal systems (EGS)

Acoculco is a geothermal system with a number of fundamental questions that need to be addressed before a development of stimulation scenarios is meaningful. Once all required data are available, an optimized EGS stimulation design for Acoculco will be developed using an existing or a new well, while honoring environmental safety and public engagement. The design will be supported by integrated, numerical, coupled modeling. The input for the models will be based on the results of the resource assessment and reservoir characterization, including characterization from deep structural imaging, chemical analysis, temperature, and in-situ stress-field as well as on rock and fluid properties. Potential drill targets/paths will be proposed to develop the reservoir using “soft stimulation” approaches. For the development of a successful “soft stimulation” approach at Acoculco, the experience from the Pohang EGS project site in Korea and from other tests performed within DESTRESS will be taken into account. For this purpose, Hofmann et al. (2018) designed a cyclic injection protocol and an advanced traffic light system, which was successfully applied to mitigate seismic events above a site-specific target threshold. This approach will be further tested and refined, if appropriate.

Concepts for the development of superhot geothermal resources

Planning concepts for the development of superhot resources include a number of high-temperature approaches and techniques, both for laboratory testing and for downhole monitoring and installations. To characterize the physical properties of rocks at conditions above the critical point of water, high-temperature and high-pressure lab measurements were designed. A new experimental set-up, especially built for these measurements, enables flow-through experiments on rock samples under controlled confining and pore pressures at near critical temperature (Kummerow and Raab, 2015). The experience gained in supercritical geothermal systems (Reinsch et al., 2017) will be transferred to the site in Mexico, and a concept for utilization will be developed for the superhot wells at Los Humeros.

Models of the geological structure will be generated including gridded properties and concepts of the volcanic situation. Based on this first modeling step, dynamic models will serve to simulate the most reasonable multi-phase conditions and the fracture properties at higher pressures and temperatures. The outcome will allow conclusions on the thermal-hydraulic-mechanical situation in the target area. Within this model of the potential drill target we will investigate at least one potential drill path. The feasibility includes knowledge of material properties, which is required in this system. Therefore, special experiments are performed in existing geothermal wells in order to test the reliability of different materials. This will be part of a list of key requirements and recommendations for design and well completion.

The plans for drilling and completion of the superhot wells profit significantly from the experience gained in previous projects in Iceland (IDDP 2) and Italy (DESCRAMBLE). Critical points to be observed include not only the choice of suitable casing material to resist the aggressive chemical environment, but also cement and couplings to compensate for the thermal expansion associated with well testing and operations at these elevated temperatures.

Environmental, social and economic impact assessment

Social impact has been addressed and public acceptance has been monitored intensively within GEMex, especially at the area of Acoculco, where currently no geothermal operations exist. Particular emphasis was on the rights of the indigenous population. Environmental impact needs to be assessed at both sites. The objective is to develop, calibrate and test a model that can subsequently be used to monitor the possible consequences of the introduction of new geothermal energy technologies, in particular EGS and SHGS. The typical result of this activity would be a series of scenarios of future impacts (for both technologies), an assessment of the state of development of the green innovation system for geothermal energy technologies, a proxy measure of the ex-ante and ex-post impacts of the technology.

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