# PROGEO: an advanced tool for geothermal energy exploitation

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## ABSTRACT

Most fluid dynamics models currently used on geothermal networks are applied in a mono-component version. The strong difference in temperature, pressure and chemical composition of geothermal fluids flowing from a geothermal reservoir to the surface equipment requires detailed models. The latter can improve the economic benefits and reduce the environmental impact. A predictive capability of the multiphase flow behaviour on wells, pipes and other components requires a complex analysis to help the design process and the management of plant operations. PROGEO is a new simulation platform recently developed for the design and installation of geothermal powerplants. The numerical code simulating the multiphase dynamics can control and predict the performance of the process and the specifications of the geothermal plant. The code has been validated on both data available in literature and real-world test cases. The back-end of the platform is based on a cloud computing concept, and it enables to manage input data, simulation process and results from any remote device, through a web user interface. It allows to carry out both design activities and monitoring the geothermal plants production, also optimizing different operational solutions.

## 1. INTRODUCTION

The flow of a multiphase stream is a complex phenomenon and applies to process components and to transport systems as well, with several order of magnitude difference in scale. Many studies have been conducted on the modelling of mass and heat flow during fluids transport from reservoir to surface, considering both one-dimensional and multidimensional approaches. Several computational models of multiphase flow for piping networks and process plants are reported in the technical literature. Some of them are developed only in stationary conditions, others are parallelized computational models. The latter have an appropriate computational capability but are designed for fields not applicable to geothermal power exploitation. On the other hand, there are models for the analysis of multiphase systems in different areas, which are however designed mainly for the analysis of processes typical of power generation plants, with low degree of applicability to the development of a geothermal field. Despite IEA foresees in 2030 a tripling of current geothermal generation (the installed geothermal capacity in the European Union to 28 states currently amounts to 1850 MWe and generates an annual output of electricity over 12 TWh), this lack of modelling and simulation tools entails that geothermal plant and networks design is still approached by mostly in house tools, seldom qualified by third parties, with low calculation power, no distributed access for team working, and no capability of forecasting plant behaviour for design optimization and safety analyses. To answer these needs, the project PROGEO has been proposed and funded by Tuscany Region (Italy) under POR-CREO-FSE financing program. The proposed project will implement the industry 4.0 approach to the geothermal systems design, trough the realization of an up-to-date engineering application, to be used for exploiting geothermal resources both for power generation and for district heat usage. The main innovative features of PROGEO is the integration on a single platform of a computational engine, a cloud infrastructure for data management, interfaced by a WEB GIS application remotely accessible through a WEB browser, suitable for design purposes (for engineers), for planning activities (managers) and for informative actions (decision makers), sharing input data, assumptions and methodologies. The final goal is to achieve results aligned with economical resources availability, social requirements and environmental and safety regulations. PROGEO, once released, will provide to engineers:

- A massive parallel calculation engine to design, monitor and optimize geothermal plants and network distribution system, based on an advanced flow simulator model;
- A cloud-based infrastructure to store, manage and distribute model calculation results;
- A web-based application for design phase and forecast representation of system behaviour and performances.

PROGEO is an innovative platform for geothermal engineering applications being:

a) Tailored, since it is specifically designed for power plants and urban districts geothermal energy design.
b) Integrated, since it includes in the same tool three crucial capabilities: design, optimization and management.
c) Predictive, since the network/geothermal plant behaviour is simulated on a medium/long-time scale.
d) Reliable, being based on well-known technologies, and developed by a consortium with demonstrated high level of knowhow on required project fields;
e) Simple and User-friendly: in a single application are available design control and prediction capabilities, making consistency among project data, design methods and obtained results. This allows to minimize implementation or analysis errors and to increase design accuracy

In Section 2 the main features of the numerical code underpinning the PROGEO platform are described. Section 3 reports the results of the project PROGEO presently achieved, while future work and next project milestones are described in Conclusions section.

## 2. MAST CODE

As introduced in previous section, the modelling engine of PROGEO platform is based on the numerical code MAST (*Multiphase Flow Analysis and Simulation of Transitions*), developed since 2005 by TEA SISTEMI (Bonizzi et al. 2009) and validated and used by that company to deliver consulting services on energy field.

MAST is a transient one-dimensional multi-phase flow simulator, which is based on dynamic pattern recognition capabilities, whereby the prediction of the relevant flow regimes which generate along the line is automatically captured, provided that fine enough computational grids are utilized (of the order of some pipe diameters). All relevant flow patterns are described, namely the stratified, annular-dispersed, slug and bubbly flows. The mathematical modeling is based on a multi-field approach, whereby separate transport (i.e. conservation) equations are written for each relevant field (i.e. continuous and dispersed); from a numerical view point, MAST adopts a first order upwind scheme for the discretization of the convective (i.e. spatial) terms, and a fully explicit scheme for the integration of the terms over time. The only equation which is semi-implicitly solved is represented by the pressure equation, which is derived from a pressure-velocity coupling algorithm. A remarkable feature of the simulator is that the user has the possibility to select, from an internal library, some constitutive (i.e. closure) laws, such as the equations used for the calculation of the friction factors. The relevant simulation capabilities of the software can be summarized as below:

i. simulation of 2(gas-liquid)/3(gas-oil-water)/4(gas-oil-water-dense fluid/foam) phase flows;

ii. simulation of multi-phase flows with:

- prescribed bulk properties;
- single and multi-component fluids Operational modules: pigging, multi-pigging, foam-pig modules are available;
- simulation of steady and transient conditions;
- process equipment: valves, check valves, PID/manual/emergency/pressure safety valve/ controllers, flow mixer, multiphase, ESP pumps, simplified centrifugal pumps, booster pump, gravitational horizontal gas-oil-water separator;
- network module for three-phase and four-phase flow systems; which allows solving for both distributing (i.e. diverging) and gathering (i.e. converging) systems.

A large database of either experimental and field test data have been used to validate MAST code performances (Faluomi, 2017). An example of code capabilities in simulating a real transient along a multiphase transportation network is reported in Figure 1, where the comparison among experimental and calculated outlet flowrate is reported.

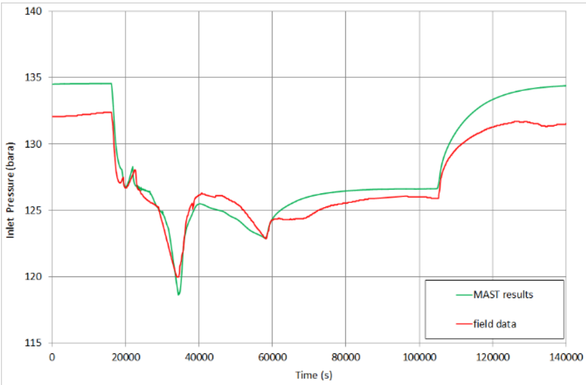


**Figure 1: MAST vs. experimental data comparison of a simulation of shutdown/restart procedure of a multiphase network.**

During PROGEO project, MAST has been modified to be applied on applications typical of geothermal plants and network. In particular, the main modification concerned model part for the identification of the phase transitions of the component. As a matter of fact, the main difference between a mono-component fluid and a multicomponent fluid is that in the first case the phase transition occurs, for each given temperature, to one and only one pressure value. Hence, from a thermodynamic point of view, while in the multicomponent case the sole fluid PT (pressure-temperature) diagram is sufficient to determine the gas phase volume fraction, in the single-component case the PT diagram can be used only to identify the limit between the possible liquid states sub-cooled, superheated steam, or saturation condition, but it is not a sufficient condition to determine the title of the phase.

Therefore, in the single-component version of the model, the PH (pressure-enthalpy) plane is used in order to characterize not only the specific thermodynamic state under which the fluid is located, but (in case of saturated water), to quantify the volume fraction of vapor at a given instant. This aspect is crucial for the resolution of the model, since the instant knowledge of the vapor content is of fundamental importance for the calculation of the evaporation/condensation rates, which in turn represents a well/source term in the equations describing the mass balance. During the project activity this modification has been tested and validated using synthetic cases, selected *ad hoc* to verify the effectiveness and efficiency of the code.

## 3. PROGEO WEB-USER INTERFACE (WUI)

The web-user interface of PROGEO is based on a web-GIS platform developed by the partner GIS3W. It serves to manage all the main phases of a project execution, namely:

1) Define a geothermal the project, associating the metadata of the designer and/or project manager.
2) Draft the network of pipelines, drawing directly on the map visible on the screen.
3) In the above task, during tracking each line, the software calculates automatically the altimetric profile of the line, by intersecting the geometric object drawn by the User with a DEM (Digital Elevation Model), provided as input by the User. This feature allows to skip the involved process of manual entering the information on line elevation and profile (Figure 2).
4) Assign several types of components that can be associated to each line, for instance: valves, controllers, pumps, etc. (Figure 3)
5) Input all the attribute (numerical data and options) to each line and/or components. These data will be then translated in inputs needed by the MAST code.
6) Save the project and translate it in a MAST model.

All data input by the User are saved in a Postgres/PostGIS database (PostGIS 2019). The information stored in this database is then processed and transformed in input files for the MAST code, through the application of an API (Application Programming Interface), named *pymast*, written in Python language (Python 2019), developed internally by the partner TEA SISTEMI to manage MAST simulations.

Once the MAST model is created, and after the code execution, the User can visualize and post-process the results via the WUI as well. In particular, several pieces of information can be visualized as tables and/or saved as text file, for further analysis. In the meantime, plots of the main variables can be visualized directly form the WUI, as *trend plots* (namely plot of a variable versus time, at a given position in the network) or *profile plots* (namely the value of a variables along a line, at a given time), as shown in the example reported in Figure 4 and Figure 5.

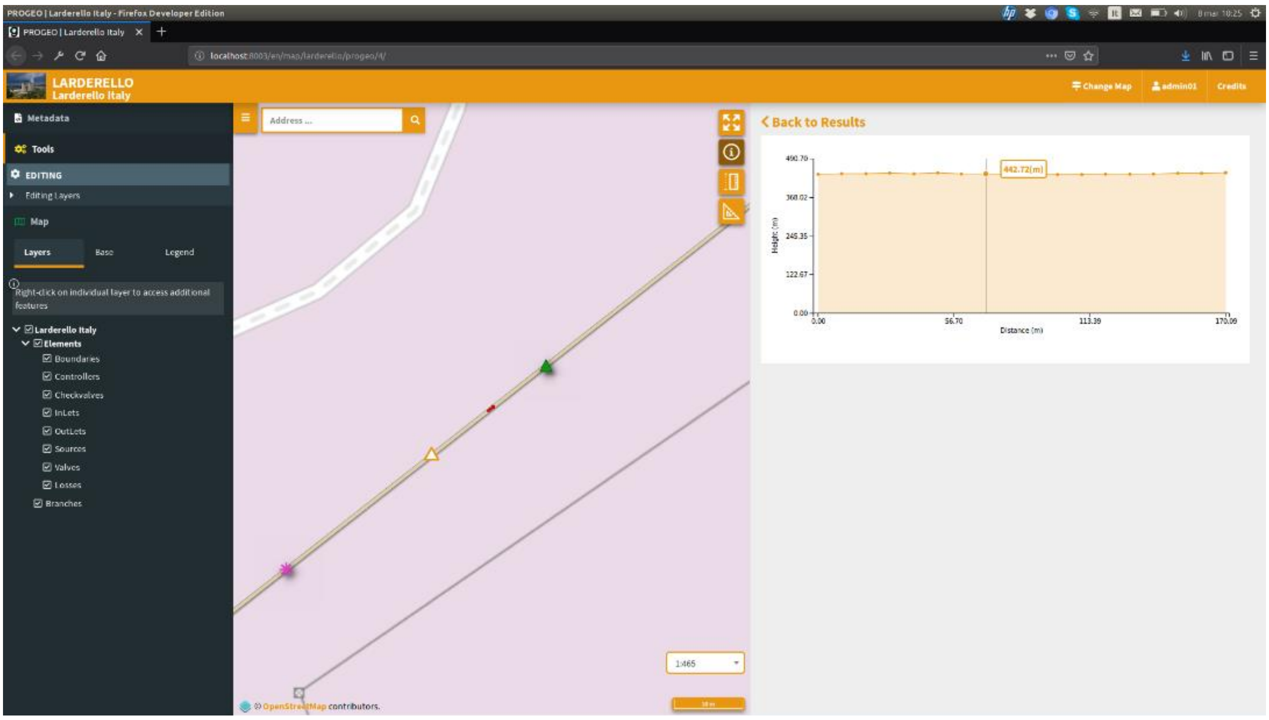


**Figure 1: A screenshot showing the preliminary version of the PROGEO WUI: drawing pipelines and getting the altimetric profile.**

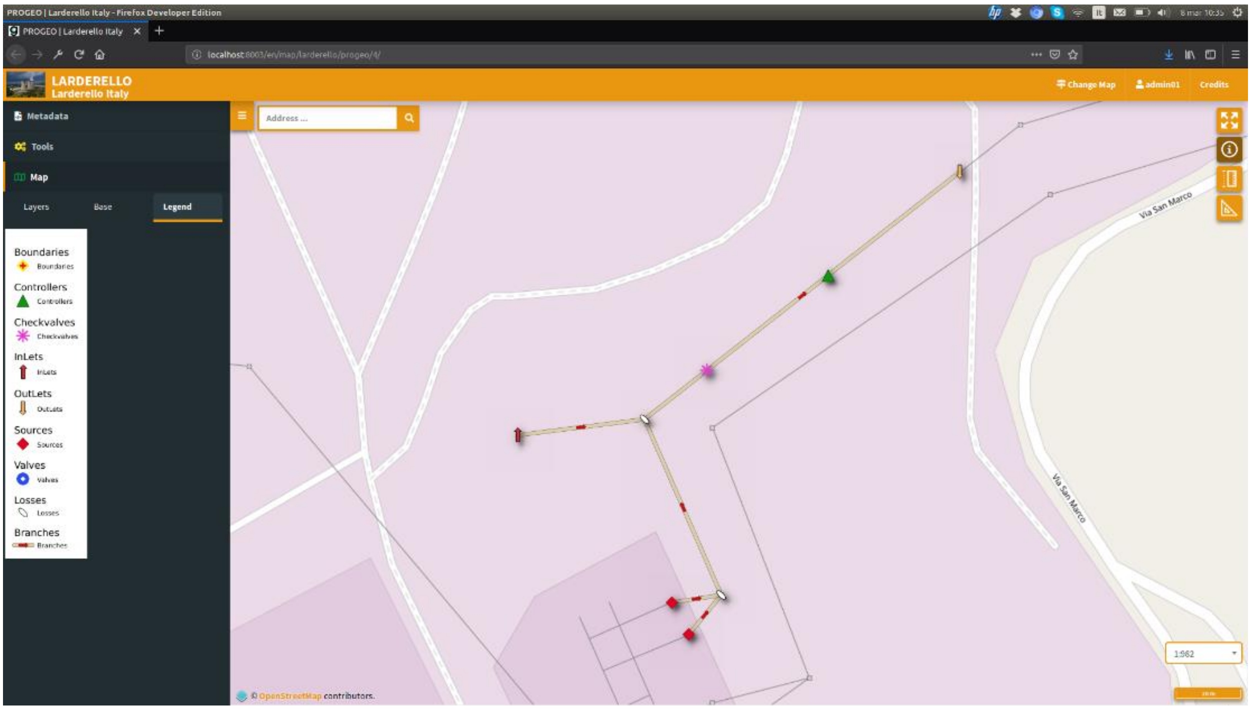


**Figure 2: A screenshot showing the preliminary version of the PROGEO WUI: including and managing components.**

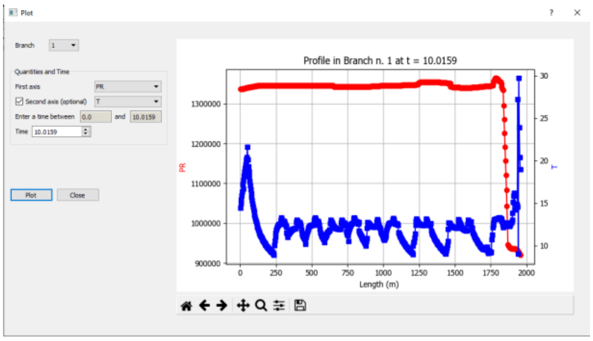


**Figure 3: Example of getting profile plots along a pipeline (for a given time).**

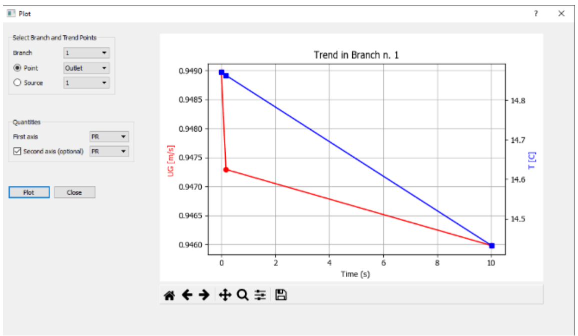


**Figure 4: Example of getting trend plots (variable vs time) at a given point in the network.**

## 3. CONCLUSIONS

Currently (March 2019), PROGEO project has achieved the main milestones expected for the first three project activities, namely the modification of MAST code, its testing and the preliminary version of the web interface. The project timeline (ending in December 2019) foresees a deep testing of the user interface, made on real-world geothermal project dealt by partner STEAM: this phase will ensure the complete feasibility of using PROGEO as effective tool in geothermal plant design and management.

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