Modelling of a Low-Enthalpy DHE Geothermal System for Greenhouses Heating: Thermal and Fluid Dynamic Analysis with FEM Approach

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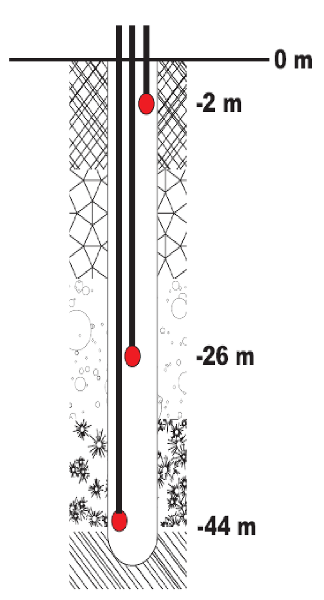
Introduction

Energy demand has been growing during the last years. Directive 2009/28/CE and Energy Roadmap 2050 have been drafted to identify the main targets in terms of energy consumptions and efficiency, following the new international awareness in matter of pollution reduction. The main targets of the European Directive and International policies are the reduction of gas emissions and general energy efficiency improvement [1]. That's the reason why petroleum-based fuels are now faced by biofuels, produced by residual biomasses. At the same time, many other renewable energy sources have been studied to optimize conversion processes they are involved in. Renewable resource advantages are mainly its abundancy, its direct use and its easy exploitation in the most cases. Therefore, geothermal energy can be considered as a renewable energy resource. Geothermal plants extract underground thermal energy by using heat exchangers to produce electricity or provide heat to domestic/industrial buildings. In this sense, a sustainability assessment framework for geothermal energy project is required [2]: many efforts to exploit geothermal potential have been made in many countries to reach new energy policies requirements. Low enthalpy geothermal plants should be considered as a suitable solution for industrial and residential buildings heating. Hydrothermal basins are usually characterized by a temperature between 40°C and 80°C, and so this makes them unsuitable for GCHP systems coupling, in this case, it is necessary to choose whether to cover the low external heat demand (e.g. by greenhouses, small houses and buildings) by directly withdrawing the basin water or installing a DHE. The choice depends both on the reservoir charging modes and thermal response stability: extracting underground water could highly affect geomorphology and soil stability. Moreover, even if a basin water refill is provided, feeding fluid temperature should damage the temperature stability of the underground reservoir. To avoid these problems, a DHE system is a suitable solution, since its installation eliminates the problem of geothermal fluid disposal.

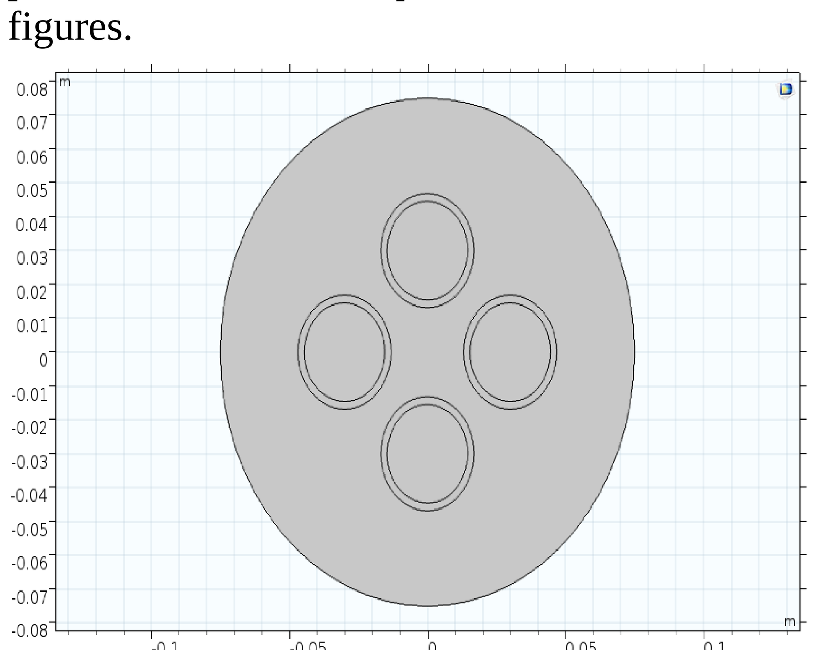
The aim of this work is to implement a multi-physical FEM model, to compute the heat transfer and the flow rate in a DHE plant which provides thermal energy to greenhouses. The proposed model has been validated by using experimental data from an experimental DHE pilot-scale plant (located in Viterbo, Italy) as a reference. Geothermal plant simulation should provide relevant information to optimize and check the thermal response of the system [3]. Moreover, the greenhouse heating process should be modified to suit plants' demand in terms of growing environmental parameters. In those cases, no high temperatures are required, so a low temperature source, such as low enthalpy geothermal systems, should be considered as a suitable solution. The experimental plant's monitoring and data acquisition have been used as a starting point while implementing the model. Furthermore, acquired temperature trend over time has been used to validate numerical values resulting from the computed scenario. Stationary studies have been solved, in order to analyze operating regime effects on temperature and flow field. Those analysis have computed the temperature trend within the pipe, considering fluid path from inlet to outlet sections; flow velocity has been also investigated to show fluid motion field fluctuations related to stagnation areas.

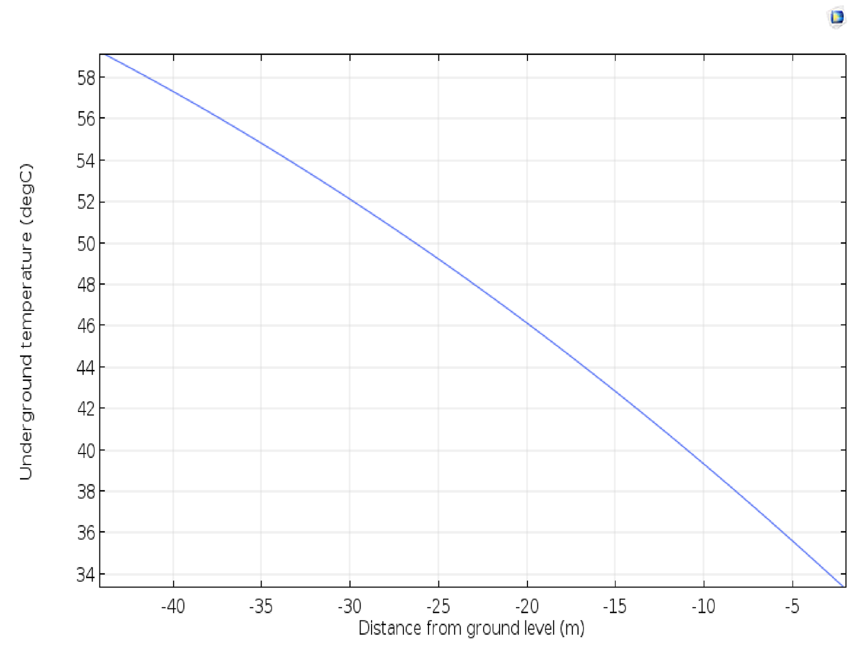
Materials and methods

The experimental campaign started with the well opening and securing. U-pipe downhole heat exchanger was inserted into the well and connected to an external hydraulic circuit installation, used to feed the DHE and change its configuration. The drilling of the well led to a 60 meters depth perforation, with a diameter of 150 mm. Due to the high presence of gases inside the groundwater basin, the water column is kept below the ground. Moreover, the underground basin pressure led to the water reservoir eruption once the aquifer has been opened during the drilling procedure. Then, resistance temperature detectors (RTD) acquired the underground water reservoir temperature. In detail, three temperature probe sensors were inserted into the U-pipe as reported by the schematic on the left.



The DHE is a steel pipe, with a total length of 50 meters and a 4,6-mm thickness, considering an outer diameter of 33,7 mm. The flow section has a diameter of 29,1 mm. Pipes location on a cut plane to describe the aquifer dimensions and the temperature trend over depth are available in next figures.

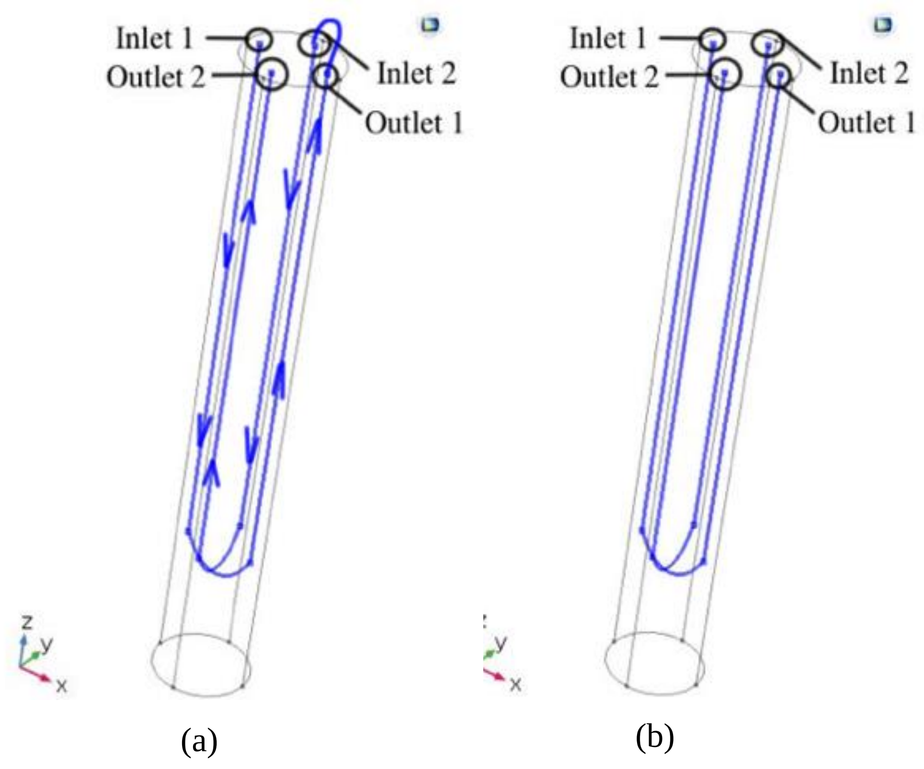




The hydraulic circuit has been designed to allow both parallel and serial configurations, referring to the water flux within the pipelines.

A stationary study was solved: in this case no time dependent effects have been considered, because a stationary regime could be considered while the DHE is working [4]. The establishment of a stationary regime along the DHE in-pipe flow was deduced from the acquired outlet temperature trend, which remains almost constant once operational regime has been reached. Finally, simulation scenarios were compared with experimental acquisitions to be validated.

Comsol Multiphysics (CM) has been used as a Finite Element Method (FEM) simulation software to solve the numerical scenario.

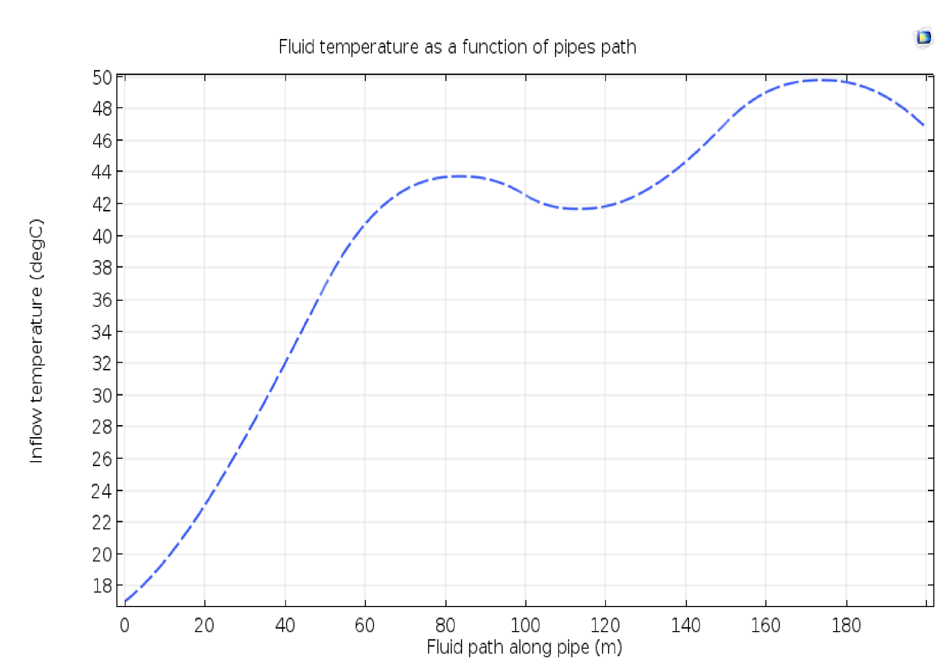


Implemented DHE system geometry configurations of pipes (in blue), not scaled: (a) serial configuration, (b) parallel configuration.

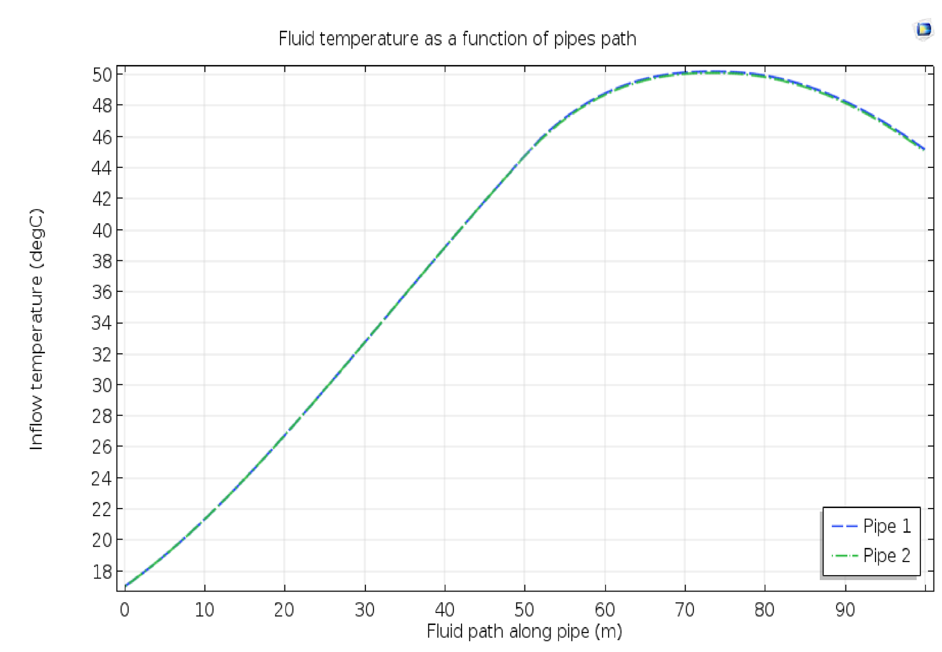
Results

The temperatures of the water flow $T(s)$ and its mean velocity $\bar{v}(s)$ were investigated, defining s as the arc length of the pipelines. Those characteristics were strictly related to the operating conditions of the reference DHE experimental plant, used as a validation case study. To confirm the consistence of the simulation scenario, the temperature trend as a function of pipeline length has been plotted for both serial and parallel configurations, as shown by the following figures.

Because of the imposed inlet temperature constraint, inlet temperature remains constant. No numerical instabilities could be noticed, both for serial and parallel configurations. The parallel configuration is characterized by the presence of two inlet and outlet sections, since the flowrate is divided into two different streams at the inlet sections. Typically, this is the main role of a parallel configuration, processing a higher flowrate by dividing it into more flows. The temperature trend of the parallel configuration in-pipe flow shows how the difference between the fluid temperatures along the pipelines path is so small as to be neglected (<1°C). At the outlets nearby the fluid has reached a higher temperature than the aquifer near the surface, so a brief cooling process should be appreciated. The arc length related to the pipelines is different between serial and parallel configuration, because of the hydraulic circuit structure: the connection between outlet 1 and inlet 2 has been taken into account for the serial configuration. A flow field analysis was also conducted to compute in-pipe fluid velocity, once Navier-Stokes equations have been solved.



Temperature trend along the pipeline (serial configuration).



Temperature trend along the pipeline (parallel configuration).

A comparison between numerical and experimental results is given by the next table.

	Serial configuration		Parallel configuration	
Parameter	Numerical	Experimental	Numerical	Experimental
Inlet temperature (T_{in})	17,0°C	17,0°C	17,0°C	17,0°C
Outlet temperature (T_{out})	45,9°C	45,6°C	45,1°C	44,7°C
Gap ($\Delta T = T_{out} - T_{in}$)	28,9°C	28,6°C	28,1°C	27,7°C
Difference between gaps	0,6°C		0,4°C	

Conclusions

The simulation scenario is validated since the divergence between numerical results and experimental acquisition is less than 1,1%. Then, it allows us to consider this FEM scenario as a useful DHE design and testing tool, once pipes geometry and underground temperature rise with depth are known. The thermal response of the system could be obtained by the temperature and flow field within the down-hole heat exchanger, resulting from the numerical scenario computation. By modifying input parameters, such as inlet temperature, underground temperature gradient, in-pipe fluid properties and flowrate, geometrical features of the heat exchanger and its configuration, the user could compare different DHE design solutions and choose the most convenient in terms of economical or performance benefits, meeting the requirements of the greenhouse plants growing process. Sensitivity analysis should be conducted to compute numerically geothermal system response to input parameters fluctuations, avoiding any deviation from the operating conditions of the on-site hydrothermal basin based geothermal plant.

Relevant References

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