Efficient Energy Supply from Ground Coupled Heat Transfer Source

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Abstract. The increasing demands of Energy for industrial production and urban facilities, asks for new strategies for Energy sources. In recent years an important problem is to have some energy storage, energy production and energy consumption which fulfill some environment friendly expectations. Much more attention has been recently devoted to renewable energies [1]. Among them energy production from geothermal sources has becoming one of the most attracting topics for Engineering applications. Ground coupled heat transfer might give an efficient energy supplies for well-built construction. At a few meters below the earth's surface the underground maintains a constant temperature in a approximation through the year allowing to withdraw heat in winter to warm up the habitat and to surrender heat during summer to refresh it. Exploiting this principle, heat exchange is carried out with heat pumps coupled with vertical ground heat exchanger tubes that allows the heating and refreshing of the buildings utilising a single plant installation. This procedure ensure a high degree of productivity, with a moderate electric power requirement compared to performances. In geographical area characterize by specific geological conformations such as the Viterbo area which comprehend active volcanic basins, it is difficult to use conventional geothermal plants. In fact the area presents at shallow depths thermal falde ground water with temperatures that varies from 40 to 60°C geothermal heat pumps cannot be utilized [2]. In these area the thermal aquifer can be exploited directly as hot source using vertical heat exchanger steel tubes without altering the natural balance of the basin. Through the heat exchange that occurs between the water in the wells and the fluid that circulates inside the heat exchanger, you can take the heat necessary to meet the needs. The target of the project is to analyze in detail the plant for the exchange of heat with the thermal basin, defining the technical-scientific elements and verifying the exploitation of heat in the building-trade for housing and agricultural fields.

Keywords: heat, thermal aquifer, thermal energy.

1 Introduction

The geology of the volcanic basin area in the Italian region of Viterbo, defines a situation which is very rich and unique, from the point of view of energy source, but it

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is difficult to be approached with the conventional low-enthalpy geothermal systems for domestic, industrial and agricultural applications.

Ground water springs, are a constant feedback with limited depth and a temperature range from 40 to 60 degrees centigrade[3].

Therefore, the respective locations of these volcanic basins, do not allow for usual exploiting geothermal technology, but require a series of experiments and devices aimed at the following tasks:

1. heat transfer with vertical closed-loop equipments
2. avoid the depletion of the source or aquifer
3. operate with highly environmentally friendly technologies
4. avoid drawing groundwater, so that the balance of drawing is only the heat exchange
5. develop technologies able to harness the gaseous fluids in groundwater and not allow the release of the same
6. develop technologies aiming at low cost installation and operation
7. develop technologies which can be suitable also for small systems or livestock farm or isolated residential unit
8. Developing technologies in synergy with photo-voltaic production and/or wind, solar thermal productions.

The economic structure of the Viterbo province, mirrors the national trend in developing localized companies with small and medium size.

Specifically, this province is characterized, in agriculture, by a high concentration of poultry and sheep farms whose maximum demand is their need to produce and store thermal energy for heating during winter months[4].

The widespread presence on the territory of thermal aquifers represents a possible optimal solution compatible with this kind of economics.

The main task of this research is to give a feasible answer to the specific requests of rural companies in the Viterbo province, and to develop well coded solutions suitable for the whole national territory.

This research aims to consolidate the technical-scientific knowledge for the exploitation of the aquifers, even very deep, by using vertical probes respectful of the aquifer, and operating only the heat exchange without dispersion of thermal water [5]. The purpose of this study is to assess, from a theoretical point of view, the rate of heat transfer undertaken in the experimental plant. These computations will make it possible to develop the optimal heat-transfer technology which could be used for allowing a minimal intervention both in relatively small settlements such as villas or apartments and in large plants demanding higher volumes such as residential buildings or animal farms and greenhouses.

The system to be assessed during this initial phase, to be implemented during the experimental tests, is made by “U”-like steel probes inside a thermal pit, designed in a such way to ensure heat exchange by contact without interfering on the thermal aquifer energy balance[6].

In particular, this work intends to compute the theoretical amount of heat which can be drawn from the geothermal wells, and also intends to present the engineering components which are needed for the realization of experimental trials.

1.1 Regulations and Laws on the Production of Low Enthalpy Geothermal Energy

The electricity obtained from geothermal energy source was produced in Italy for the first time in 1904 in the Tuscany town of Lardarello, which is located on the same geological hydrothermal area of Viterbo (see Fig. 4)[7]. At that time, Italian regions were ruled by different laws resulting from the application of the existing regulations inherited by the Italian unification. In many regions, including Tuscany, which owns more than 90% of Italian geothermal resources, outweighed the interests of landowners. This means that they possessed the land and nothing could be extracted from underground [8]. However, the division of land among different, often fighting, landholders has hindered the development of mining and geothermal energy exploiting since the landowners even did not possess the technical knowledge and financial resources.

That is why in 1927 the Italian government, passing by the abolition of existing laws and the constitution of a single national law, thought it was necessary to regulate mining together with the exploitation of geothermal energy, so that the responsibility is enrolled by the mining activity[9].

Thanks to the new legislation "*the rights of landowners must be closely linked to the needs of the community*" so that "*the exploitation of the subsoil is independent on the surface profits*" and, as a consequence, the title of the property itself.

Thanks to this law the Ministry of National Economy, was solely responsible for relations between Researchers and / or landowners in respect of the development of coal mining.

Currently, the Italian legislation on the exploitation of geothermal resources is governed by the following laws:

- Regio Decreto 29 luglio 1927, n. 1443: "Legislative rules to govern the exploration and production of mines in the Kingdom" posted in Gazz. Uff. 23 agosto 1927, n. 194.
- DPR 9 aprile 1959, n. 128: Police regulations about mines and quarries, published in Gazz. Uff. 11 april 1959, n. 87,S.O.
- In 1986, a new law was approved aiming to accommodate these new needs arising, in particular, from the method of exploitation of geothermal resources. The main concerns of this law can be found in: *Art 2. Inventory of geothermal resources". Art. 4. Research permits and provisions to safeguard integrity both of the environment and urban settlements. Art. 5. Extent and duration of the exploration license. Art. 11. Provisions to safeguard the integrity the environment, to keep the eco system ecological balance and the integrity of city planning.*
- Constitutional Law, October 18, 2001, n. 3 titled "Changes to Title V of Part II of the Constitution" art. 3, This law establishes the matters of exclusive legislation of the State, as regards the energy sector which is the sole responsibility of the State and give rules for "*transport and distribution of energy";*

Some Interesting rules for the low enthalpy geothermal energy are contained in the law **L. 99/2009** entitled "Provisions for the development and internationalization of enterprises, and energy", where the deployment of low enthalpy geothermal plants are given.

The use of low enthalpy geothermal plants is included in all legislation concerning the rational use of energy which were ratified in recent years.

In the wake of the regional legislative autonomy all Italian regions have a role in regulating their own exploitation of geothermal sources. As an example the Region Lombardia, with law n. 1 of 05/01/2000 identifies those functions transferred or delegated to local authorities with the autonomous activities and those kept in the head region. Tuscany Region also specified the competence and the authorizations necessary for the construction of geothermal plants (see following table).

Type of Plant	Authorization	Procedure
Depth below < 400 m Thermal Power < 2.000 Kw t Without fluid withdrawal	Regional (Artt. 11 e 15 L.R.39/05)	Application to Regional Administration through a specific form required to the region
Depth below < 400 m Thermal Power < 2.000 Kw t Without fluid withdrawal	Regional (Artt. 11 e 15 L.R.39/05)	Application to Regional Administration. Region will activate a unique procedure concerning all duties.

2 The Basic Model of Heath Exchange with Natural Convection

The thermal energy used is transferred by natural convection from the thermal water to the heat exchanger in the well. The heat exchanger consists of a U-shaped tube where inside there is, as circulating fluid, water [10].

The testing system is simulated by a tank containing hot water at rest in which is inserted a U-shaped tube exchanger.

Because of the geology of the area identified for the trial, it is assumed that the water temperature of the well is constant [11].

The starting point is the general equation for heat transfer across a surface which is:

$$Q = A \cdot U_D \cdot \Delta T_{LM} \tag{1}$$

Q : heat transferred per unit time, W
A : heat-transfer area, m^2
U_D : overall heat transfer coefficient, W/m^2 ^{o}C
ΔT_{LM} : mean temperature difference, the temperature driving force, ^{o}C :

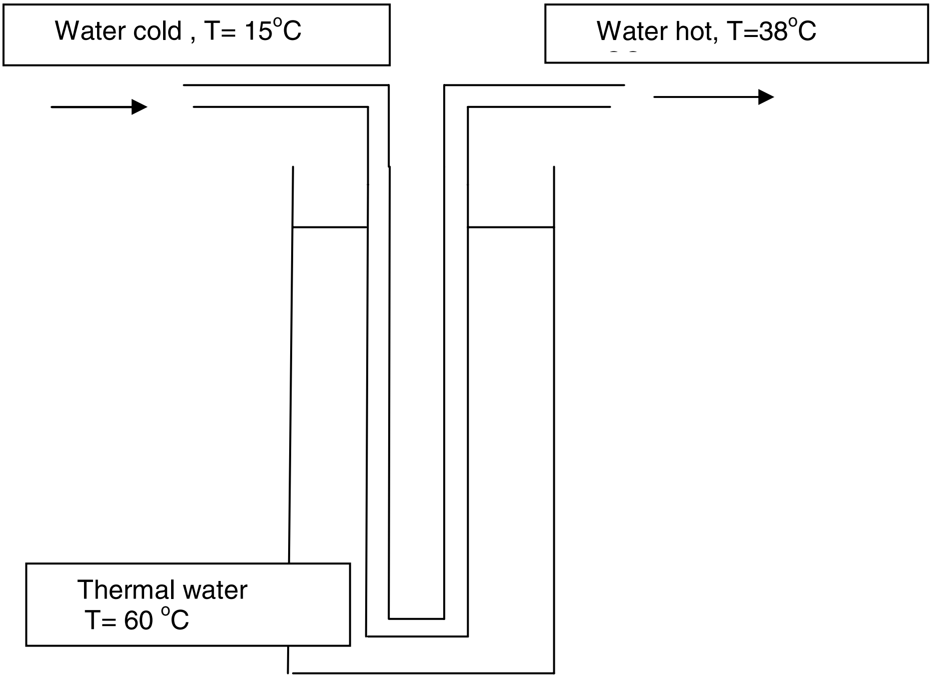

Fig. 1. Schematic heat exchanger in the well

$$\Delta T_{LM} = \frac{(T - t_2) - (T - t_1)}{\ln\left[\frac{(T - t_2)}{(T - t_1)}\right]} \tag{2}$$

T : temperature hot fluid
t_1 : temperature cold fluid, in the feeding pipe
t_2 : temperature cold fluid, in the outgoing pipe

For the heat exchange across a typical heat-exchanger pipe the relationship between the overall coefficient and the individual coefficients, which are the reciprocals of the individual resistance, is given by [12]:

$$\frac{1}{U_D} = \frac{1}{h_{i0}} + \frac{d_0}{2k}\ln\frac{d_i}{d_0} + \frac{1}{h_0} + R \tag{3}$$

U_D : the overall coefficient based on the outside area of the tube, W/m^2 °C
k : thermal conductivity of the tube wall material, steel 50 W/m °C
d_i : inner pipe diameter, m
d_0 : outer pipe diameter, m

h_{i0} : outside dirt coefficient (fouling factor), W/m^2 °C
h_0 : outside fluid film coefficient, W/m^2 °C

R : dirt factor pipe for water 0,0002 ($m^2h\ ^oC/kcal$) for T < 50°C and 0,0004 ($m^2h\ ^oC/kcal$) for T>50°C

The temperature reached by the heat-carrying fluid outgoing from the pipe should be at least about 38° C, the minimum value needed to activate the low temperature heating systems. The value of heat needed to warm up the water is given by:

$$Q = c_p\ w\,(t_2 - t_1) \tag{4}$$

c_p : specific heats water, (J/kg °C)
w : flow water, kg/s.

From this equation it is possible to compute the heat available from the heat exchanger, at a fixed geometry, being the size of the well given.

2.1 Heat Transfer Coefficient

The first step is to calculate the overall heat transfer coefficient according to the following scheme:

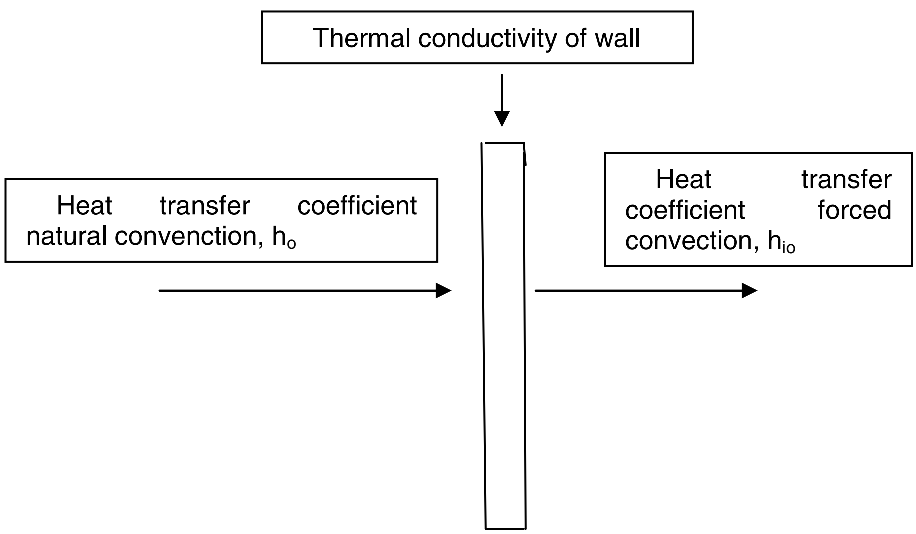

Fig. 2. Heat transfer coefficients

2.1.1 Forced Convection

Inside the pipe the heat transfer is due to a forced convection, since the fluid is pumped into the tube.

The heat transfer coefficient is given by the equation:

$$h_{i0}\left(\mathrm{Re}\right) = \frac{1}{d_{i0}} k^{2/3} c_p^{\ 1/3} \mu^{1/3} \left(\frac{\mu}{\mu_0}\right)^{0.14} J_h\left(\mathrm{Re}\right) \tag{5}$$

d_{i0} : outer diameter, m
k : thermal conductivity for water, 0.68 W/mK
c_P : specific heats water, 4196 J/kg °C
μ : viscosity for water, $0.38 \cdot 10^{-3}$ Pa·s
J_h : heat transfer coefficient, J_H=f(Re)
Re : Reynolds number

Reynold number is defined as:

$$\mathrm{Re}=(v d_i \rho)/\mu \tag{6}$$

being
v : velocity of the heat-carrying fluid outgoing from the pipe
d_i : inner pipe diameter, m
ρ : density
μ : viscosity.

The fluid motion in a duct is considered laminar if the numerical value of Re is less than 2100, turbulent if more than 10000. Transition regime is when 2100 < Re <10000. The heat transfer coefficient J_H might assume different values depending on the type of motion of the fluid inside the tubes:

$$J_h(\mathrm{Re})=\begin{cases} 1.86\left(\mathrm{Re}\dfrac{d_i}{L}\right)^{1/3} & , \quad \mathrm{Re}<2100 \\ 36.45-\left[36.45-1.86\left(\mathrm{Re}\dfrac{d_i}{L}\right)^{1/3}\right]\left(1.2658-1.2658\,10^{-4}\,\mathrm{Re}\right) & , \quad 2100<\mathrm{Re}<10000 \\ 0.023\,\mathrm{Re}^{0.8} & , \quad 10000<\mathrm{Re} \end{cases} \tag{7}$$

2.1.2 Natural Convection

Inside the shaft there is thermal water which is not forced to move by any external action, the only present are convective motions which are consequence of local variations in density. Convective motions are the only responsible for heat transfer. The coefficient of transmission outside a horizontal tube immersed in a liquid at rest can be computed by the equation:

$$h_0=0.51\frac{k}{d_0}\left\{\frac{\left[d_0^{\,3}\rho^2\,g\,\beta\left(T_0-T_p\right)\right]c_p}{\mu\,k}\right\}^{1/4} \tag{8}$$

k : thermal conductivity
d_0 : outer pipe diameter, m

ρ : density
g : gravity constant, 9.81 m/s^2
β : coefficient of expansion
T_p : temperature outside the wall pipe
T_0 : temperature water in the well
c_P : specific heat of the water
μ : viscosity coefficient

All parameters have to be evaluated at the average temperature of the film T_f which is established between the tube wall and fluid at rest.

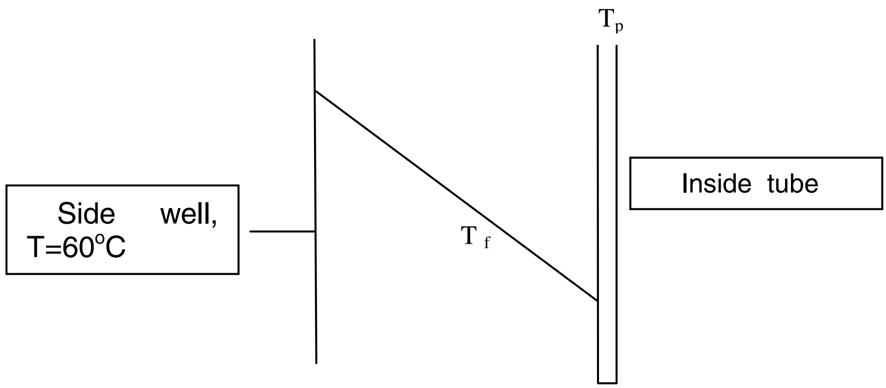

Fig. 3. Scheme heat exchange in the film

The average temperature T_f of the film can be obtained by successive approximations from the equation

$$h_{i0}\left(T_i - T_p\right) = h_0\left(T_0 - T_p\right) \tag{9}$$

T_i : mean temperature of the fluid inside the pipe
T_p : temperature wall
T_0 : mean temperature of the water in the well,

with

$$T_p = \frac{h_{i0}T_i + h_0T_0}{h_{i0} + h_0} \tag{10}$$

$$\overline{T}_f = \frac{T_p + T_0}{2} \tag{11}$$

T_f : mean temperature of the film

$$\beta = -\frac{1}{\rho}\frac{d\rho}{dT} \tag{12}$$

ρ: density, $\rho = f(T)$

$$\rho = 1.00504 - 0.000422027\,T \tag{13}$$

2.2 Computation of the Heat Exchange

For the theoretical calculation of the heat, which can be taken from the well, the spring was considered at a constant high temperature (hot water). This assumption is supported by the presence in the area of high volcanic activity.

Input values:

$w = 0.1$ kg/s
$c_p = 4196$ J/kg °C
$t_1 = 15$ °C
$t_2 = 38$ °C
$T = 60$ °C
$P = 1000$ kg/m^3
$\mu = 0.38 \cdot 10^{-3}$ Pa·s

According to (4), the heat Q which is required to warm up the fluid (water) from the temperature T_1 to temperature T_2 is,

$$Q = 9650.8 \text{ W} \tag{14}$$

The amount of heat, taken from a fixed geometry given by the U-shaped tube inserted into the well, might be computed from Eq. (1).

For the calculation of A is necessary to know the size of the U-tube:

d_{io} = 33.7 mm
d_i = 29.1 mm
L = 110 m, pipe length

$$A = 23.21 \tag{15}$$

The logarithmic mean temperature difference is:

$$\Delta T_{ML} = 24.2 \tag{16}$$

Thus we have to proceed with the computation of the overall heat transfer coefficient, according to Eq. (3). In particular, the coefficient of heat transfer fluid inside the pipe depends on the Reynolds number [13]:

$$Re = 11563 \quad . \tag{17}$$

In presence of phase then the coefficient of heat transfer and (5) give:

$$h_{io} = 1096.72\ W/m^2K \tag{18}$$

Regarding the coefficient of heat transfer fluid outside the tube which is in natural convection, it can be obtained from (8) by successive approximations.

The coefficient of thermal expansion and density, have to be computed at the temperature of the film:

$$\beta = \frac{0.000422027}{1.00504 - 0.000422027\,T} \tag{19}$$

By successive approximations we have obtained the following values for h_o:

h_o	T_P	T_f	ρ	β	$h_{(o)}$
800	40.66	50.33	0.9837	$4.28 \cdot 10^{-4}$	27.218
27.218	32.57	46.285	0.9855	$4.28 \cdot 10^{-4}$	29.71
29.71	33.02	46.51	0.9854	$4.28 \cdot 10^{-4}$	29.59
29,59	33.002	46.501	0.9854	$4.28 \cdot 10^{-4}$	29.59

The global coefficient of heat transfer, considering all factors of (3) [14]:

$$U_D = 28.63\ W/m^2\ {}^oC \tag{20}$$

Heat Q can be detected from the well through the heat exchanger as given by (1):

$$Q = 16080.95\ W \tag{21}$$

According to the value calculated in (14) we have assumed both that the heat exchange system is sufficient to warm up the water for the low temperature heating system and there is a very low total pressure lost in the pipes:

$$\Delta P = 1.69 \cdot 10^{-2}\ bar$$

3 Models and Methods

We propose the realization of an experiment to assess the amount of heat that can be taken from a thermal spring in which hot water is present. Heat is taken without draining-off the water.

The trial involves the carrying out of several steps needed to proceed in a rigorous evaluation of the heat taken from the well. In particular, once opened, the shaft will be inserted by instrumentation for monitoring water temperature and the heat exchanger performances. The whole plant will be equipped with instrumentation able to control temperature and flow rate which are necessary to known for the calculation of heat that can be taken from the well [15].

It is also planned a preliminary measure of thermal activities of the neighboring wells in order to have a clear idea of the temperatures involved and about the possibility of identifying potential changes related to testing under consideration.

The experimental program will be implemented as follows:

- Opening and securing the well: Once the well has been opened, the water at the surface mouth well will be lowered and the water loss repaired
- Insertion of monitoring equipment in the well before the activation of the pilot plant it is planned a series of measurements concerning the characteristics of the well needed to measure the temperature gradient and the organoleptic characteristics of the thermal water. It is also expected to monitor the temperature of thermal basins adjacent to the shaft. By using these data it is possible to test the impact on environment, concerning the heat draw from the well.
- Construction of the geothermal plant: it involves the insertion of 4 probes that will be prepared on site, through the implementation of the joints necessary for assembly. Special pieces will be realized in loci. The probes are designed in a such way that they can be used either in series or in parallel in this way one can check the best link that provides the highest heat exchange. Controls are provided both for temperature and flow on the outlet and the return of the probes inserted necessary to verify the heat. The fluid used inside the probe is water which is taken from the cold sink. It has been also provided a device enabling the heat flow in order to make it possible to measure the heat exchange.
- Simulation by the software TRNSYS of the conditions under which the heat exchange is realized. Based on data collected during the test, some simulations will be carried out on computer to ensure the maximum efficiency of the plant.

3.1 Description of the Site and the Well

The well, interesting to experiment, is located at the hatchery at the center of the basin in the City of Viterbo (Fig. 4). As one can see from Fig. 4 Viterbo is located in one of the most active geothermal Italian areas.

Well looks like an artesian well of 150mm in diameter and a depth of about 60m, at the wellhead is located a steel tube bent at the summit needed to hold the swing of thermal water up to 1.5 m from the surface. In the vicinity of the well there is both the water supply to be used as heating fluid and the electric current needed to feed all utilities for running the plant activity [16].

3.2 Description of Measures and Controls

To conduct the experiment it is necessary to examine in detail the internal temperature of the well, and the characteristics both input and output of fluid in the plant. For this reason, it is envisaged the use of three temperature probes to be inserted at regular

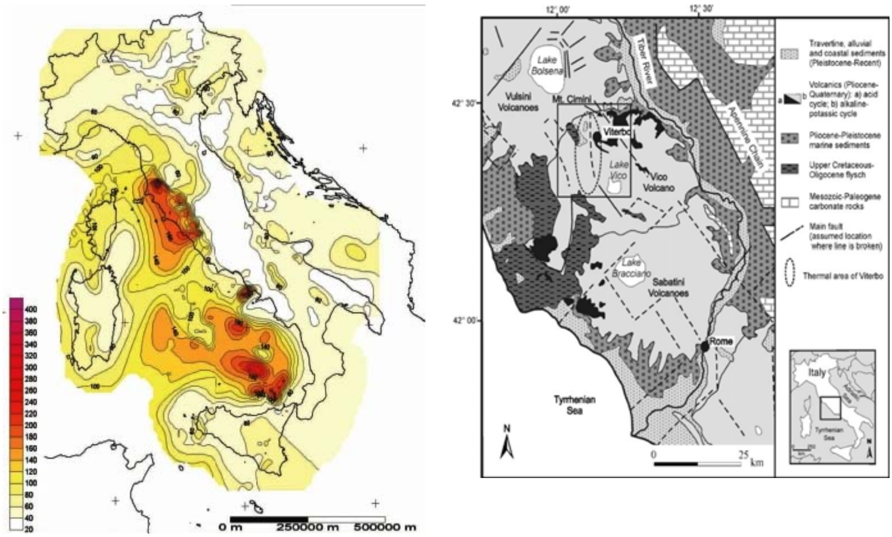

Fig. 4. Viterbo hydrothermal area within the regional geological picture[16]

intervals within the well, so that one can see and measure the temperature inside the well. There will be, at constant time intervals, some sampling to evaluate pH, electrical conductivity, density and salinity. These parameters are needed to evaluate the possible corrosion of the materials included in the well.

All sensors involved in the experiment need a framework for acquiring and monitoring data [17].

The framework consists of a fiberglass container with two compartments, one containing the industrial PC and the other a PLC that contains the electronics interface.

From the main monitor some cables connect the data acquisition devices. This configuration it is also ready for future implementation of automation systems and control valves, for the use of heat exchangers in series and parallel, and the choking of the flow into exchanger according to parameters set.

Furthermore, this system provides for controls of the temperature and flow on the outlet and the return of the heat exchanger [18]. These measures are necessary to calculate the heat exchanged in the well, thus enabling us to verify the temperature reached by the fluid circulating in the exchanger.

3.3 Plant Description

The heat exchanger to be undertaken consists of vertical U-shaped steel probes that may have different geometries [19]:

- a single U-shaped pipe: inside the same drill it is placed both the ongoing tube and the outgoing tube which are connected at the bottom.

- a double U-shaped pipe: is realized as the previous one, except that in the drill there are four tubes pair wise connected at the bottom.
- coaxial pipe: the outgoing tube is inside the ingoing tube. The diameter of the ingoing tube nearly coincide with the diameter of the drill.
- coaxial pipe with complex geometry: similar to the previous one with the only difference that between the inside and outside tubes there are some connecting wings enabling a better heat exchange. The returning fluid instead of the inner pipe can circulate in some of the peripheral channels so that it can exchange heat with the ground in both directions of its circular path [20].

In the first analysis was assessed the amount of heat taken from the U-shaped pipe inserted into the shaft, the tube used has the outer diameter of 33.7 mm and the inner diameter of 29.1 mm, it provides a length of heat exchange along 110 m.

4 Conclusion

Based on the calculations we have done, we have shown that, from a theoretical point of view, the designed heat exchange, in the given conditions, is sufficient to warm up water for the realization of a low temperature heating system. We have made several assumptions in the evaluation of heat transfer from the system, which however must be verified during the experimental trials. The first parameter to be checked is the water temperature of the well, in fact, in the design it is assumed to be constant along the entire length of the heat exchanger. We can predict that surely there will be a temperature gradient as a function of the depth of the well. It should be also verified the variation in time of the heat exchange temperatures.

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