Geothermal fields

Special zones: geothermal fields

Zones that are characterised by a high and anomalous heat flux are those where the release of energy from the ground is greater, however to be able to use this source a fundamental ingredient, together with hot rocks, is water.
Water heats up thanks to the contact with hot rocks below the surface and, if the temperature and pressure conditions allow it, it can even turn into steam. In order to understand the phenomena in these anomalously hot zones, we must recall that the temperature at which water turns into steam depends on the pressure: when pressure measures 1 atm, vaporisation temperature is, as we know, 100 degrees Celsius, but at 10 atm (equal to the pressure of a 100 m water column, o about 30 m of rock), it goes up to 180° C. In this way, therefore, high pressures keep water at the liquid state even at much higher temperatures than those 100° C that we associate with water boiling in a pan!
The areas where a high heat flux warms the subterranean waters are called geothermal fields and are generally distinguished in high and low temperature geothermal systems (also called high and low enthalpy systems). In these areas it is possible, with the right technologies, to exploit the Earth's natural energy to produce electricity, for domestic heating and for many other industrial uses: an available for free and renewable energy source. Unfortunately, geothermal fields that are able to produce a good quantity of energy are not many, in the world.
How does a geothermal field look like?
All geothermal systems' structures look a bit like hydrocarbon traps and the techniques to individuate them, which use geophysical prospecting, are also very similar to the ones used in petroliferous research.
A geothermal system is constituted by:

- a **source of heat** (for example, magma undergoing a cooling process);
- an **aquifer**, that is a permeable geological formation, where water can infiltrate and circulate freely through pores or fractures;
- an **impermeable cover rock** that acts as a "trap" for the hot waters, preventing their dispersion on the surface and keeping them under pressure.

Finally, in order to allow a lasting exploitation of this energy source it is necessary to have a constant refill of water coming from the surface, generally meteoric waters, that can "refill" the aquifer, integrating the water drawn by man: where this is not so, it is necessary to input fluids artificially.

High temperature geothermal systems

In high temperature geothermal systems, the underground waters are very hot, usually, over 140 ° C. Temperatures can be even higher, such as, for example, in Larderello (Toscana) (260° C), Cerro Prieto (Messico) (388° C) or S. Vito (Campi Flegrei, Campania) (400 °C): the latter area has registered the highest temperature ever observed in a geothermal system. In these systems the heat flux is 3-4 times higher than normal and can generally be found in correspondence with cooling magma intrusions, between 3 and 15 km of depth. Geothermal systems can present both an ascent of "dry" and overheated vapour, in the absence of liquid water (this constitutes the so called "vapour-dominated systems"), and an ascent of a mix of liquid water and vapour ("water-dominated systems"). Vapour, drawn through wells and systems of pipes, is used to give power to a turbine system, which in turn produces electricity. Vapour-dominated systems are the most productive, because in water-dominated systems the liquid phase has to be separated and eliminated and this entails an expenditure of energy. Vapour-dominated systems are quite rare and there are only four, spread around the globe: Larderello and M. Amiata (Italy), The Geysers (California), Matsukawa (Japan) e Kawah Kamojang (Indonesia), while the most important water-dominated ones are in Wairakei (New Zealand) and Cerro Prieto (Mexico). The production of electricity from geothermal fields is an Italian initiative: it started in Larderello in 1904, followed only many years after by the Wairakei plants (New Zealand) in 1958 and The Geysers (California) in 1960: Italy was a precursor in the exploitation of geothermal energy and to this day our country is one of the major world producers. Currently the main producers of geothermal electricity are, in order of productivity, the USA, followed by the Philippines, Indonesia, Mexico, Italy, New Zealand, Iceland and Japan. The discovery of new geothermal fields is an exceptional event, however technological research allows a continuous increase in productivity of the existing fields.

Low temperature geothermal systems

In low temperature geothermal systems, where temperatures are below 140° C, direct production of electricity from vapour is not generally convenient. However, if temperatures are above 90° C it is possible to use warm fluids to vaporise a second fluid that has a lower boiling temperature (such as freon, isobuthane or ethyl cloride), thus obtaining vapour for indirect electricity production, even if the productivity level of this process is rather low.

Hot waters though lend themselves to a variety of uses, with a “cascade” scheme, that first uses hot fluids in applications that require higher temperatures, and then reuse them, in applications that require lower temperatures, as they get cooler. Its primary application is for urban heating, for which water between 130° C and 50° C can be used. Hot water fields are used for domestic heating in various states around the world, especially, in order of importance, in Japan, China, Hungary, ex- URSS, Iceland, Poland, France. The first experiments of geothermal heating for domestic usage took place in Iceland in 1930: in this country, a significant part of the capital’s houses heating comes from low-energy geothermal fields. In Italy this method is applied, for example, to hotels in the thermal area around Abano Terme (Colli Euganei, Veneto) and many buildings around Larderello (Tuscany).

A "cascade" of applications

After being used for electricity production and domestic heating, geothermal fluids still have a certain quantity of heat that allows their usage in a variety of ways, some of which very peculiar: in Sapporo (Japan) and Klamath Falls (USA), for example, hot waters are used for **heating the roads** during the winter to avoid the formation of ice.

Various productive processes benefit from the use of geothermal waters. For example, special absorption systems for refrigeration with ammonia or lithium bromide used for cooling and summer air-conditioning are obtained from hot waters, if the temperatures are between 80-120 °C.

Among the productive uses, agriculture and zootechnics are the sectors where the use of geothermal energy is more immediate and advantageous. The hot waters are used for direct heating in greenhouses: very well-known examples are the Piancastagnaio greenhouses (M. Amiata, Toscana), or the Colli Euganei (Veneto) cultivations of ornamental plants. In countries where the climate is particularly cold, such as, for example, Siberia, the hot waters are made to circulate in a system of pipes that are in contact with the ground, the so called “hot beds”, obtaining the heating of the cultivated ground, which allows cultivation even under conditions that would otherwise be prohibitive for agriculture.

The warmth that is produced by contact with hot waters is exploited for all zootechnic and agricultural processes that require a warm environment, such as, for example, mushroom cultures, fish and animal breeding and egg-hatching in

poultry farms.
Other uses in the agro-alimentary sector regard wood and fish dehydration, the preparation of tinned food, the production and seasoning of dairy products or sugar refining, while more industrial uses regard the production of heavy water, aluminium, cement production processes, tire vulcanization and many others.
The waters that circulate deep underground are often rich in salts and minerals: these can represent a problems, in terms of pollution, but they can also become an important resource, as for instance for the extraction of suplhur, boron and metals. We must not forget the therapeutic uses. The habit to go to thermal baths was spread in Europe by the Romans, who exported it in all the territories they conquered, but it has been present in Asia for centuries: only in Japan there are more than 1600 thermal centres, some of which have very ancient origins. In Italy thermal complexes are about 170 and they are exploited not only for the heat of the waters, but also for the therapeutic effects of the minerals present in them. The benefic effects of a thermal bath are wll known also by the macaque population of the Nagano springs, in Japan, who bathe there during the winter months to keep warm: the funny images of the little animals happily lying in the warm water, with the coat covered in snow and red snouts, have gone all around the world and now the Nagano macaques have become a famous tourist attraction, so much so that, in typical oriental fashion, an area of the thermal baths has been reserved for them only!

Our local systems

Italy, because of its geological situation, is rich in both high- and low-temperature geothermal fields. The “symbol” and flagship of the geothermal energy in our country is definitely represented by the Larderello-Travale-Radicondoli thermal field, in Tuscany. Here electricity was produced for the first time in the world, but the exploitation of the “soffiones” goes back to the Middle Ages, for the production of sulphur and sulphuric acid, and, from 1780 onwards, for the production of boric acid. If the resource is entirely Italian, the first use of thermal energy for boric acid extraction was enacted by a Frenchman, Mr. De Larderel (who gave the name to the place), since the vapours of the soffiones are rich in boric acid. The first experiments of electricity production took place in 1904 and the first production plant was born in 1913, with a capacity of 250 kW, but it was only since 1930 that electricity production became an important part of the renewable energy sources of our country. With a capacity of 790 MW, exactly 100 years after the first experiments, geothermal energy in Italy reached in 2011 its maximum productivity level, with a production of 5300 GWh, net of consumption of auxiliaries. Research in this field hasn’t yet stopped: currently a 3D seismic prospecting is being realised, associated to the perforation of 11 new deep wells (of between 3.000 and 4.000 m of depth): in the last 5 years, a total of 21 wells has been realised, with an overall length of 64 km! The second “historic” Italian geothermal field is situated not far from Larderello, on M. Amiata, where electricity is produced by an 88 MW plant. Apart from electricity production, the Tuscan plants provide water for domestic and greenhouse heating, for dairy production and fish farming and fuel the production of CO_2 and boric acid. Recently other interesting fields have been discovered in Lazio (Alfina e Cesano) and in the Campi Flegrei area (Napoli), apart from the Colli Euganei area (Veneto) and around Ferrara. Fields of hot water have been discovered in the Pianura Padana subsoil, at S. Donato Milanese (Lombardia), between 1900 and 2400 m, with temperatures between 70 and 80 °C, and similar fields have been detected in the subsoil of Villaverla and Vicenza (Veneto) and Ferrara (Emilia Romagna). In the subsoil of the Casaglia area (Ferrara), where carbonated aquifers with a temperature of 100° C have been found at 1200-2000 m of depth, one of the most important projects of geothermal district heating in the world is being realised, which entails the heating of tens of thousands of houses.

Clean energy?

Geothermal energy is universally considered a clean energy. The characteristic that makes this source renewable and preferable to the others is its constant availability. In fact in the case of geothermal energy , electricity is available 24/24h, 365 days a year. In its natural condition, the geothermal fluid is present in the reservoir in the form of steam, as is the case in Italy in Larderello; or in the liquid form as on Mount Amiata. In both situations, a layer of impermeable rock isolates the geothermal reservoir from the water of the surface aquifers. Steam is generally associated with other gases, such as H_2S and CO_2 in variable amounts, and it is the percentage of these so-called non-condensable gases associated with the temperature of the fluid that subsequently determines the possibility of reinjecting or not reinjecting all the fluid to recharge the reservoirs again.
In order to extract this fluid with maximum respect and protection of the surface aquifers, the wells are shaped like upside-down telescopes, to guarantee the absence of geothermal fluid contamination as it moves to the surface. In this course, the fluid changes state and partially transforms into steam. Consequently, a mixture of steam is obtained, characterized by a high temperature and therefore a high energy content. For fluids of this type, all over the world, a circuit with direct steam admission and evaporative type cooling towers is utilized. The fluid coming from the well is forwarded to the power plant through an integrated fluid transportation network which has been designed and created choosing courses that follow the morphology of the land and vegetation, exploiting the discontinuities for a better insertion. Furthermore, in the tracts that are more visible, plant screens are created in order to reduce the visual impact of the geothermal fluid extraction and transportation operations. From the steam pipes, the high-temperature fluid is forwarded directly to the turbine, and electricity is generated.
The fluid is then channelled to the condenser where the steam returns to the liquid state while the gas is separated and then treated.
The new generation power plants in Italy are provided with the best technologies available in the environmental sector. The treatment is carried out using AMIS technology for the abatement of hydrogen sulphide H2S and mercury emission. The process enables the abatement of a very high percentage of mercury and hydrogen sulphide. The water extracted from the condenser is sent to a wet cooling tower where it cools by evaporation. The part that evaporates newly in the process is released in the atmosphere while the surplus liquid part is reinjected in the geothermal reservoir.
The new generation cooling towers are designed in avant-garde technology plants, with very high efficiency equipment to eliminate the droplets in the atmosphere, the drift, and with low-noise fans; they are also much smaller than those of the past and are much more compatible with the surrounding landscape.

Energy forever?

The Earth’s energy is apparently inexhaustible, at least when measured relative to human age span. However even the exploitation of geothermal fields must be carried out with a careful control and a sparing management of the resources. Geothermal fields tend progressively toward a natural decline that can be effectively contrasted with a studied and targeted reinjection process, through a detailed knowledge of the reservoir. An incorrect reinjection could in fact lead to a cooling, that would decrease the productivity and self-regenerating capacity of the reservoir.

New frontiers

Technological development and the need to retrieve energy from the highest possible number of sources are contributing to the rediscovery of geothermal energy and an increase of its areas of utilisation: of the “clean and cheap” energy provided by our planet, nothing is wasted! Using systems of heat pumps, which extract heat from a fluid using small

quantities of electricity, heat that is then yielded to a heat tank, waters with very low temperatures can be used for domestic heating, up to 30-40° C. The same waters can be used directly with panel heating systems instead of heaters. Currently there are studies concentrating on the exploitation of the so called hot dry rock fields. At high depths (around 5,000 m), even under normal heat flux conditions, the majority of the rocks is sufficiently hot to be able to fuel a geothermal system. If the warmth from the Earth is always available, sometimes though the other fundamental “ingredient” for the use of geothermal resources is missing: underground water circulation. In this case, nature has to be “helped” to create a tank that will aide the formation of a geothermal system: cold waters are artificially pumped into deep wells, after having seen to the fracturation of the surrounding rocks to allow the water to penetrate, in order to recreate an aquifer system similar to a natural geothermal field, from which it is possible to draw heated waters.
In some areas of the Earth, such as the Mexico Gulf, geothermal systems have been discovered at a depth of 4,000 m, where hot waters are mixed with methane at very high pressures: in this case, the exploitation would yield geothermal energy as well as significant quantities of hydrocarbons. The Hawaii islands, thanks to the heat of the various active volcanoes, also constitute a formidable experimental ground. For example, there is an ongoing experiment for the production of hydrogen from very hot waters that are heated by volcanic magma, the temperatures of which are around 900-1,200° C. What however represents the ultimate frontier in this field of research is the possibility to put organic waste in contact with hot magma to produce gaseous hydrocarbons. Will man really be able to reproduce Nature’s processes to create energy?