BAGNORE 4: a benchmark for geothermal power plant environmental compliance

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ABSTRACT

Increasing the share of energy from renewable sources can reduce greenhouse gas emissions, improve energy security for countries that lack domestic fossil fuel resources, insulate countries from fuel price volatility and foster local economy. Although renewables are clean and sustainable energy sources, their development still has an impact on the environment. Environmental impacts are always assessed prior to any decision to develop a project and possible mitigation measures are taken to foster positive impact and minimize negative aspects.

Enel Green Power has devoted a large part of its technological development to the environmental compliance of all technologies, and in particular of geothermal power plants. In the framework of a continuous improvement strategy, in addition to a maximization of plant efficiency and optimum use of the geothermal resource, which help reduce effluents, Bagnore 4 geothermal power plant has been equipped with several systems able to reduce noise, visual pollution, mercury, hydrogen sulfide, ammonia, drift emissions from cooling towers and even the reduction of steam emissions during the shut-downs.

This paper describes the main issues addressed in the Bagnore 4 project, a 40 MW single flash steam power plant located in the touristic area of Mt. Amiata, boasting a broad variety of natural habitats, which represents the state of the art of Enel Green Power geothermal installations.

1. INTRODUCTION

Bagnore 4 is a 40 MW geothermal power plant. It is located in the geothermal field of Bagnore, in the Mt. Amiata volcano complex, in Tuscany, central Italy. Monte Amiata boasts a broad variety of natural habitats, from forests of chestnut and beech to water springs and even mineral quarries. This area is known for its landscapes, traditions, history and is one of the most popular tourist destinations in southern Tuscany.

Monte Amiata volcanic cone rises 600 m about the surrounding plateau, to reach a total height of 1732 m, dominating the landscape of southern Tuscany. Monte Amiata continues to fuel many thermal springs around its base, including hot water bathing centers which make use of thermal water directly from the springs.

Both the flora and fauna of Mt. Amiata are unusual and precious, with a number of endemic species. Beech and chestnut trees cover the lower slopes of the mountain, while the higher slopes are covered with forests that are spectacularly colored in the autumn and make the mountain extremely popular among hikers.

Compatibility between the geothermal power production activity and the development or preservation of the above resources of the territory is a key issue for the sustainability of the geothermal energy and its acceptance by the communities hosting the plant.

All energy conversion systems, including renewables, lead to environmental impact. Bagnore 4, a single flash steam power plant, has been designed to minimize the majority of the possible environmental impacts for this kind of power plant both in normal operation and shut off of the generating units condition. Attention has been paid to a number of factors, including gaseous and liquid emissions, noise emissions , visual impact.

2. NON CONDENSIBLE GASES

In Italy, Enel Green Power owns and operates 37 geothermal power generation units with a total gross generating capacity of almost 800 MW, allowing an electricity production of 5,8 TWh/y.

Most of those units are 20 MW size, of the so-called “standardized geothermal unit”, suitable to accommodate different inlet steam pressures, in the range from 5 to 20 bar, while maintaining the same flow (110 to 130 t/h of geothermal steam). Geothermal fluid extracted from the Italian reservoirs mainly consists of steam with some percentage of non condensable gases (NCG) which represent 4.4% by weight (avg) in the steam fed to the turbines.

After expansion in the turbine, in a standardized geothermal unit the fluid enters a direct-contact type condenser operating at a very low pressure (about 0.08 bar absolute). From the condenser, two streams are extracted: a liquid stream, pumped to the cooling towers, consisting of the cooling water and the condensed steam, and a gaseous stream, drawn out of the condenser by means of mechanically-driven centrifugal compressors, mainly represented by the NCG.

A simplified scheme of a single flash geothermal unit is shown below (Figure 1).

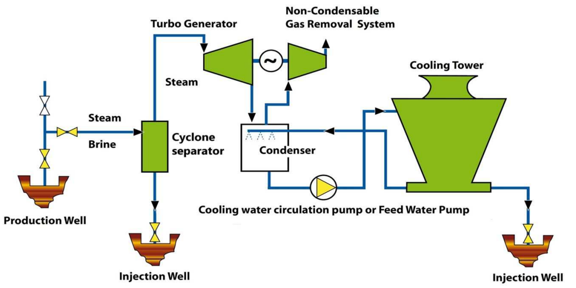

Figure 1 – Single flash unit simplified scheme.

The main concerns related to the NCG emissions are connected to the presence of hydrogen sulphide and mercury in elemental form. In the case of Bagnore, basic soluble compounds, especially ammonia, are naturally present in the geothermal water. Ammonia emissions are to be minimized too.

Although their concentrations in the ambient air are remarkably lower than the reference values indicated by the World Health Organisation (WHO) for health protection, Enel Green Power developed abatement systems to reduce emissions as much as possible.

In the case of ammonia and hydrogen sulphide, a concentration close to the respective odour thresholds could be perceived. Hydrogen sulphide in particular is characterised by an odour threshold concentration in the air of few ppb (part per billion): a very low concentration, far away from WHO reference values, could represent a real nuisance for people.

As far as mercury is concerned, although its presence is higher in Mt. Amiata area than in other geothermal fields, the emissions of this element are quite low. The only concern is related to possible build-up, in the long term operation, even at significant distances from the power plants, due to the mobility of this element.

3. NON CONDENSIBLE GASES ABATEMENT

To remove Hydrogen sulphide and mercury contained in the gaseous stream extracted from direct contact condenser, Enel developed and patented a process tailored for the characteristics of Italian geothermal power plants, namely AMIS® (acronym for Abbattimento Mercurio ed Idrogeno Solforato).

Instead of being released to atmosphere, NCG are sent to the AMIS® system for mercury and hydrogen sulphide abatement. A simplified scheme of a standard geothermal power plant equipped with AMIS® system is shown in Figure 2.

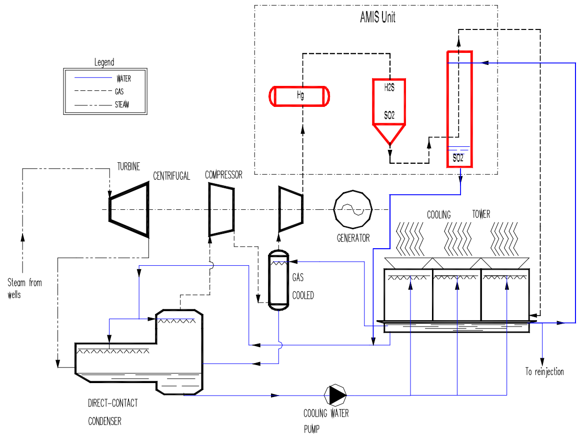

Figure 2 – A geothermal power plant equipped with AMIS®.

The figure features the three fundamental steps of the AMIS® process:

-removal of mercury by chemical adsorption;

-selective catalytic oxidation of H_2S to SO_2;

- SO_2 scrubbing by geothermal water.

Elemental mercury is removed from NCG by chemical adsorption on a fixed bed of selenium mass. Before entering the bed, the process gas is cooled in order to achieve the optimum temperature (about 70°C) for the adsorption.

The selective oxidation of hydrogen sulphide (H_2S) to sulphur dioxide (SO_2) is achieved in a catalytic reactor. By a feed-effluent exchanger, reactor feed is heated up to the minimum temperature required by the catalyst to promote oxidation according to the reaction:

$$H_2S + 3/2\, O_2 \Longrightarrow SO_2 + H_2O$$

Reaction is exothermic and the process is completely regenerative, so that no external heating is required during normal operation. To provide the oxygen needed for H_2S oxidation, air is added to the gaseous stream to be treated in the reactor.

SO_2 produced by the reaction is finally absorbed by geothermal water in a counter-current packed tower.
The efficiency of the SO_2 absorption essentially depends on the molar ratio between produced SO_2 and ammonia in the geothermal water. Depending upon ammonia content in the geothermal water, efficient SO_2 removal can be achieved without addition of any chemical.
The water leaving the absorption column, containing the reaction products of SO_2 scrubbing mainly consisting of soluble salts, re-enters the cycle of the geothermal water, controlled by the cooling tower overflow to reinjection.
An advantage of contacting SO_2 with ammonia is related to the decrease of ammonia content in the geothermal water cycle. To further reduce ammonia emission from cooling towers, sulphuric acid is injected in the cooling water stream leaving the condenser.
Sulphuric acid injection has been proved to be effective for ammonia abatement and is being used for the adjacent Bagnore 3 power plant as well.
AMIS® process exhibits very high efficiencies, close to 99% for both H_2S and mercury. To calculate the overall abatement of mercury and H_2S, also the emission related to the liquid stream leaving the condenser, which is not treated by the AMIS® system is to be taken into account.
In the case of Bagnore an overall reduction in the range of 95%-99% and 80%-90% is reported for mercury and H2S respectively.
A simplified scheme of a geothermal power unit complete with AMIS® plant and H_2SO_4 injection is shown below (Figure 3).

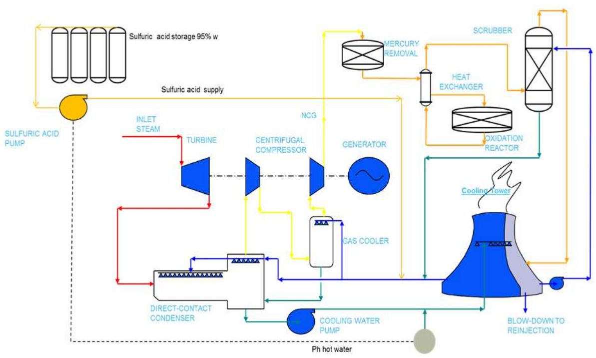

Figure 3 – A geothermal power unit equipped with AMIS® and ammonia abatement system.

4. BAGNORE 4 CONFIGURATION

Bagnore 4 power plant has been designed to include two 20 MW "standardized geothermal unit", installed close to the existing 20 MW Bagnore 3 power plant.
Such a configuration was dictated by considerations on power plant flexibility and outage reduction.
Geothermal fluid gathering system is common for Bagnore 3 and Bagnore 4, so that steam emissions to atmosphere can be reduced during the shut down of one of the three units.
Furthermore, Bagnore 4 is equipped with two AMIS® plants, connected to both power generation units and overdesigned for 150% capacity. In the case of outage of one of the Bagnore 4 AMIS® plants, this configuration allows to minimize temporary H_2S and mercury emissions.

5. LIQUID EMISSIONS

Two geothermal water dominated reservoirs are present in the Mt. Amiata field. Geothermal fluid feeding Bagnore power plants is extracted from the deeper one, and the fluid produced at well head is a two phase mixture of water and steam.
A first separation between water and steam is achieved at well head. The steam separated is sent to the power plant for power production purposes, whereas the liquid stream is re-injected in the reservoir.
The steam going to the power plant is processed:
about 75% of the water from steam condensation is evaporated in the air flow, the balance, which represents the cooling tower overflow, is re-injected through reinjection wells in the geothermal reservoir, thus contributing to the exploitation sustainability.
All the continuous liquid stream, from both well head and power plant, are therefore re-injected.
The water released to atmosphere from the cooling tower is in fact released in the vapour phase, being evaporated by the air circulating in the cooling tower.
Only the so called "drift" from the cooling tower, i.e. the liquid droplets entrained in the exhausted air stream leaving the towers, can be considered as an exception. Drift droplets contain the same chemical and salts of the circulating water from which they originate, so that their emission is to be minimized to avoid detrimental effects on the environment.
State of the art drift eliminators are installed at Bagnore 4, to limit water loss and, in turn, emissions of salts from the tower.

Figure 4 shows the drift eliminators installed, able to reduce drift emission to 0,002% of the circulating water.

Figure 4 – Drift eliminators.

6. NOISE EMISSIONS

During plant operation, noise emissions can be considered as secondary. Nevertheless, Enel Green Power paid the maximum attention to limit acoustic emissions.

The main sources of noise to be considered are related to the cooling towers, transformers and power house.

Bagnore 4 cooling towers are equipped with low-noise gearbox and fans, characterized by limited vibrations and minimum power. Water splashing in induced draft cooling towers can be a significant source of noise, particularly at short distances. Water silencers are installed to effectively reduce this noise too.

In a Geothermal power plant noise also arises from the necessity of shutting down a unit for periodic maintenance or a fault, as the steam (and noise) is generally vented to the atmosphere during shut down. A silencer is usually installed, aimed at reducing the noise emission. Figure 5 shows Bagnore 4 silencer internals.

Figure 5 – Silencer

Reduction of noise during periodic shut down is reduced at Bagnore 4 power plant by automatic wellhead valve throttling, reducing steam flow rate to be vented to atmosphere.

In case of an emergency shut down of one unit, Bagnore 4 configuration can allow to limit steam emissions and related noise by maximizing steam feed flow rate to the other units.

7. VISUAL IMPACT

Geothermal energy cannot be exploited everywhere because its presence is limited to those areas where its utilisation is economically viable. Installation in areas with energy intense industries would be preferable, to avoid thermodynamic losses and relatively long transmission lines, or to avoid building power plants in areas of touristic interest. Particularly in those cases, changes to landscape and natural features, both temporal and permanent, are to minimized.

Although geothermal energy is concentrated in the underground resource, several facilities are needed to make the reservoir available and the use of geothermal energy possible. They include access roads, steam and water pipelines, power plants. In the case of geothermal power plants, pipelines and roads can also be long and intrusive.

Several techniques have been used by Enel Green Power to minimize visual impact, land use and “surface disturbance”.

The number of wells per pad has been maximized to limit land use as much as possible and to concentrate “surface disturbance”.

Pipelines have been designed at minimal height above ground level and/or in trenches, possibly along existing roads or woods, to limit their visual impact.

Figure 6 – Pipeline trench

Figure 7 – Pipelines routing.

Power plants external colours and architectural elements were accurately selected for optimum blending with the local landscape and with the adjacent Bagnore 3 power plant, designed by the famous architect Stefano Boeri, rewarded with many recognitions in international contests was featured in architectural magazines.

Figure 8 – Bagnore 4 power plant during construction.

8. CONCLUDING REMARKS

Geothermal energy cannot be exploited everywhere because its presence is limited to those areas where its utilisation is economically viable.

Bagnore 4 is a 40 MW geothermal power plant, recently stated up by Enel Green Power in the Mt. Amiata area (Tuscany), characterised by historical and cultural heritage, high environmental quality and tourism based economy.

All systems and components of Bagnore 4 power plant, including wells, pipelines, power plant equipment and configuration have been designed to adopt the best standards dictated by EGP environmental management.

Bagnore 4 represents a benchmark for geothermal power plants environmental compliance, in a framework of continuous improvement of power plant performance, sustainability and acceptability by local communities.

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