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Greening of Geothermal Power: An Innovative Technology for Abatement of Hydrogen Sulphide and Mercury Emission

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ABSTRACT

Perfect compatibility between geothermal plants and the development of the other resources of the territory (tourism, quality agriculture, etc.) is a key issue for the sustainability of the geothermal energy and its acceptance by the communities hosting the plants. Third Millennium geothermal projects are able to win this challenge. Integration in the landscape of power plants and related infrastructures, abatement of the gaseous emission and of the cooling tower drift, reduced noise level, etc., allow the preservation of natural beauties, environmental features and life quality of the people living near the plants.

The invention of a proprietary technology (AMIS®) for the abatement of hydrogen sulphide and mercury emission and its application both to new geothermal plants and to the retrofit of the existing one's is a cornerstone of the New Geothermal Deal in Italy. Hydrogen sulphide is responsible of the bad smell often perceived in the geothermal areas. AMIS®is an environmentally friendly process because it usually doesn't require the use of chemicals and doesn't produce sulphur based by-products to be landfilled or recycled.

At present, three power plants are equipped with AMIS® systems. The results of two years of commercial operation are outlined.

1. INTRODUCTION

Geothermal energy is a renewable energy source and can therefore provide an important contribution to the sustainable development.

The first experiment on electricity generation by geothermal resources was carried out in Larderello (Italy) more than one century ago (July, 4th, 1904) when a reciprocating engine powered by geothermal steam enabled to light four small lamps. The first industrial power plant dates back to 1913; this represents the worldwide "big bang" of the geothermal exploitation for electricity generation. In 2003, electricity from geothermal resources totalled more than 5 billions kWh, which represents approximately 2% of the electricity generated in Italy. This share rises up to about 25% in the Region of Tuscany, where almost all geothermal development is concentrated, substantially contributing to the excellent sustainability balance of this Region. Geothermal generation has allowed Italy to save the consumption of 1.2 million TOE (tons of oil equivalent) of fossil fuels and to avoid the emission of 3.7 million tons of CO_2. The new geothermal plants planned for the next years will contribute to CO_2 emission reduction required to fulfil Italy's Kyoto commitment (reduction of 6.5% of CO_2 emission in the period 2008-2012 compared to 1990).

Geothermal facilities (production and reinjection wells, steam pipelines, power plants, etc.) are concentrated in small areas of Tuscany, characterised by historical and cultural heritage, high environmental quality and tourism based economy. As a consequence, geothermal development is strongly dependent on the acceptability by local communities.

Geothermal exploitation must therefore preserve the natural beauty, the environmental characteristics and the quality of life, representing an opportunity for the development of the territory, as a result of direct social and economic benefits and the availability of low-cost heat.

The major problem of the geothermal energy is related to the atmospheric emission of the power plants, mainly hydrogen sulphide and mercury in elemental form. Hydrogen sulphide is characterised by an odour threshold concentration of few ppb (part per billion), remarkably lower than the reference value of 100 ppb (as 24 hours average) established by the World Health Organisation (WHO) for the protection of the population health. Hydrogen sulphide concentrations in the ambient air, measured both by ENEL and ARPAT (the Environmental Protection Agency of Tuscany) are much lower than WHO reference value, so that this compound doesn't pose any problem for the population health. However the bad smell of hydrogen sulphide is often perceived in the geothermal areas, depending on the atmospheric conditions and represents a real nuisance.

As for mercury, the emissions of this element are quite low, but there is some concern about possible build-up in the long term operation even at significant distances from the power plants, due to the mobility of this element.

Emission cleaning and in particular the elimination of the bad smell of hydrogen sulphide is a crucial point for the perfect compatibility between geothermal exploitation and valuable use of the territory, fundamental requirement for the consensus of the local communities.

Owing to the particular features of the Italian power plants (small and unattended) and of the geothermal fluids (high content of non condensable gases), the abatement technologies available on the market were not suitable and entailed excessive costs. As a consequence, it became necessary to develop an innovative process. This objective was achieved through the invention of AMIS® technology (Abbattimento Mercurio ed Idrogeno Solforato, Abatement of mercury and hydrogen sulphide), below outlined.

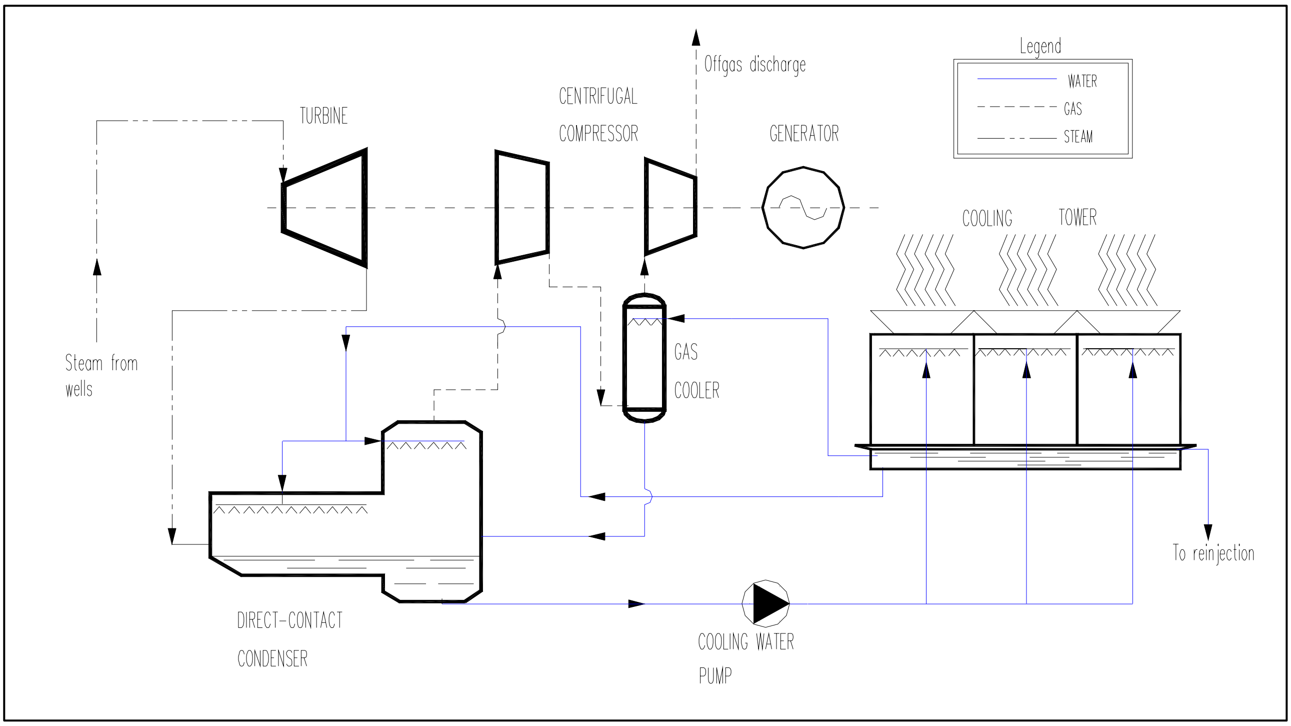

Figure 1: Simplified scheme of a standard geothermal power plant

2. HYDROGEN SULPHIDE AND MERCURY ABATEMENT

Geothermal fluid extracted from the reservoir by production wells is carried to the power plants by a steel pipe network. The fluid mainly consists of steam with some percentage (from less than 1% up to 15%) of non condensable gases (NCG).

Figure 1 shows the simplified scheme of a standard geothermal power plant not equipped with emission control systems.

After expansion in a turbine, the fluid enters a direct contact condenser operating at a very low pressure (about 0.08 bar absolute), where the steam is condensed and the NCG are cooled to reduce compression power by the cold geothermal water flowing from the cooling tower basin.

NCG are drawn out of the condenser by a centrifugal compressor and released to the atmosphere from the cooling tower.

Steam condensation increases the temperature of the cooling water. Water from steam condensation and cooling water leave the direct-contact condenser at a temperature of about 35°C. An extraction pump sends the hot water to the top of the cooling tower where it is cooled down to about 25°C by a counter-current flow of air. Cold water is collected in the tower basin to repeat the cycle.

About 75% of the water from steam condensation is evaporated in the air flow. The balance, which represents the cooling tower overflow, is reinjected through reinjection wells in the geothermal reservoir, thus contributing to the exploitation sustainability.

Instead of being released to atmosphere, NCG can be 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. The figure features the three fundamental steps of the AMIS® process:

-removal of mercury by chemical absorption;

-selective catalytic oxidation of hydrogen sulphide to SO_2;

-SO_2 scrubbing by geothermal water.

2.1 1st step: Mercury removal

Elemental mercury is removed from NCG stream by chemical absorption on a fixed bed of sorbent (selenium mass or sulphurized activated carbon). Before entering mercury absorber, the process gas is cooled and subsequently compressed in order to achieve the optimum temperature (about 70°C) and relative humidity conditions for the reaction. In addition, gas compression provides the head required to compensate the draft losses of the AMIS® system.

2.2 2nd step: Catalytic oxidation of hydrogen sulphide

The selective catalytic oxidation of hydrogen sulphide (H_2S) to sulphur dioxide (SO_2) is the second basic step of the process. NCG are heated up to the minimum temperature required by the catalyst to promote oxidation according to the reaction:

$$H_2S + 3/2\ O_2 \Rightarrow SO_2 + H_2O$$

The reaction is exothermic. The enthalpy of the hot stream leaving the catalytic reactor is recovered to preheat the cold stream leaving mercury absorber. The process is completely regenerative, so that no external heating is required during normal operation.

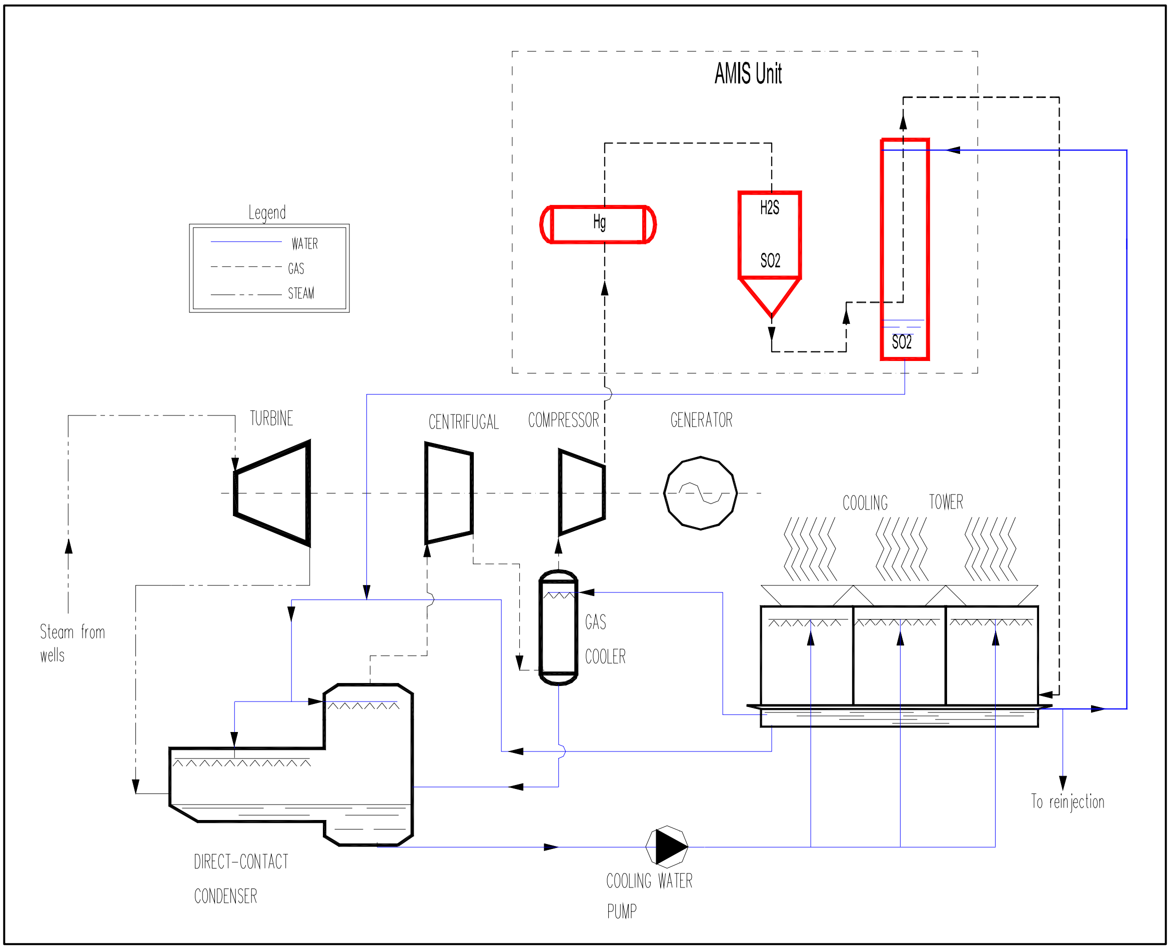

Figure 2. Simplified scheme of a standard geothermal power plant equipped with AMIS® abatement system

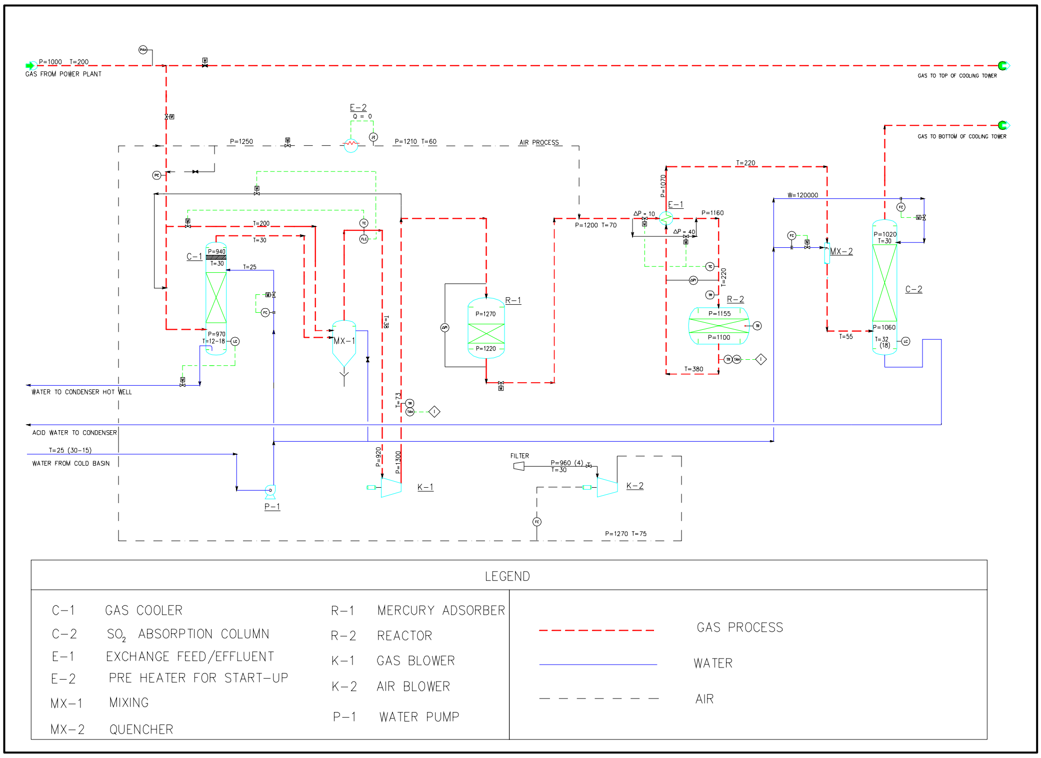

Figure 3 Simplified Process Flow Diagram of Bagnore 3 AMIS® system

Some air is added to the gaseous stream to be treated in order to provide the oxygen needed for H_2S oxidation and catalyst temperature control. Too high a temperature, in fact, causes fast catalyst deactivation or promotes side reactions, in particular oxidation of SO_2 to SO_3. Combustion of methane and other flammable compounds in NCG is anyway impossible due to the operating temperature range and to the high CO_2 concentration.

2.3 3rd step: Sulphur dioxide scrubbing by geothermal water

The final step of the process is the absorption of the produced SO_2 by geothermal water.

In most cases, geothermal fluids contain basic soluble compounds, especially ammonia, so that these are naturally present in the geothermal water. Basic compounds allow the absorption of acidic components, such as sulphur dioxide (SO_2).

In the AMIS® system, SO_2 absorption is achieved in a packed column, filled with metallic rings to enhance contact between gas and liquid phases.

The efficiency of the SO_2 absorption essentially depends on the molar ratio between produced SO_2 and ammonia in the geothermal water. If geothermal water contains enough ammonia, SO_2 removal is close to 100% without addition of any chemical. Otherwise it is possible to achieve the same result by adding ammonia water, thereby increasing the natural ammonia content of the geothermal water, or, as an alternative, sodium hydroxide (NaOH).

The reaction products of SO_2 scrubbing are soluble (sulphites, thiosulphites and thiosulphates).

The water leaving the absorption column re-enters the cycle of the geothermal water, controlled by the cooling tower overflow.

2.4 AMIS® abatement efficiency

AMIS® process exhibits a very high abatement efficiency, higher than 99% for both pollutants.

It allows an overall reduction of plant emission in the range of 95%-99% for mercury and 75%-85% for H_2S. Overall reduction is calculated with reference to the uncontrolled plant emission. It takes into account also the emission related to the liquid stream leaving the condenser, which is not treated by the AMIS® system. As a consequence, overall removal efficiency is lower than removal efficiency of the AMIS® system.

The difference in the overall removal efficiency of hydrogen sulphide and mercury is related to the different partitioning of the two compounds between the gaseous and liquid phases inside the condenser. In a geothermal plant not equipped with AMIS® system, about 95%-99% of mercury and 40%-60% of H_2S entering the plant are present in the gaseous phase leaving the condenser. The liquid phase accounts for the balance of H_2S and mercury , which are released to atmosphere after stripping by the air flow inside the cooling tower.

In case of a geothermal power plant equipped with AMIS® system, pH reduction of the circulating water, caused by SO_2 scrubbing, changes H_2S partitioning, so that 75%-85% (depending on the geothermal water composition) of the total hydrogen sulphide evolves in the gaseous phase extracted by the compressor. This increases the share of H_2S treated by the AMIS® system and thus the overall removal efficiency.

2.5 Awards and patent

In 2003, AMIS® process awarded the Italian “Prize for Environment and Innovation” by Polytechnic of Milan, Bocconi University of Milan and Legambiente, one of the major NGO for the environment.

AMIS® is a patented process (Inventor: Dr. Aldo Baldacci; patentee: ENEL SpA).

3. AMIS® SYSTEM OPERATION RESULTS

The first full scale AMIS® system was commissioned on February 2002 as retrofit of Bagnore 3 geothermal plant, located in southern Tuscany, with a nameplate capacity of 20 MW(e). A simplified Process Flow Diagram of the system is shown in Fig. 3.

The geothermal fluid feeding Bagnore 3 plant is produced by a water dominated field. NCG content of the fluid is in the range from 5% to 12% by weight, depending on the production wells feeding the plant. Therefore, the AMIS® system is designed for a maximum NCG flowrate of 15,600 kg/h, with a turn down of 1:3.

Average H_2S and Hg concentration, on a dry gas basis, are 1% v/v and 2.5 mg/Nm^3, respectively.

The main characteristics of Bagnore 3 power plant and of the AMIS® system are summarised in the following table:

Bagnore 3 geothermal power plant		
Nameplate capacity	20	MW
Steam flow at full load	130	t/h
Bagnore 3 AMIS® system		
Maximum NCG flowrate	15,600	kg/h
Turn down	1:3	dimensionless

Although both mercury removal systems above described (based on sulfurized activated carbon and selenium mass) were installed, selenium mass only was used during the first period of operation.

AMIS® system performance has been carefully monitored during the first two years of operation, in order to confirm the validity of the process and to gather useful information for the design of future abatement systems. The measured removal efficiency of both H_2S and mercury from the NCG sent to the AMIS® system was about 99% or higher in the long term operation.

Overall reduction of plant emission was 95% or higher for mercury and 75% for H_2S.

Fluid feeding Bagnore 3 plant contains a lot of ammonia (molar ratio H_2S/ammonia about 1:3). This on the one hand allows a complete scrubbing of SO_2 without chemicals addition and on the other hand increases the buffer capacity of geothermal water. As a consequence, pH decrease after SO_2 scrubbing is moderate, limiting the partitioning change towards gaseous phase. This is the reason why overall H_2S removal efficiency is limited to 75%.

The main results of two years of operation of Bagnore 3 AMIS® system are shown in the following table:

		Without AMIS	With AMIS*
Gas treated by AMIS	kg/h	-	8000
H_2S flow at turbine inlet	kg/h	100	100
H_2S flow at compressor exhaust	kg/h	44.8	75
Conversion efficiency of H_2S to SO_2	%		99
SO_2 removal efficiency	%		>99
Hg flow at compressor exhaust	g/h	10	10
Hg removal efficiency	%	-	>95

AMIS® system operated unattended, reaching the design turn down.

Following these very positive results a second AMIS® system was commissioned in July 2003 to clean the emissions of two power plants, Travale 3, rated 20 MW, and Travale 4, rated 40 MW. These power plants are very close each other, enabling to install a single AMIS® system for treating the emissions of both plants. The capacity of this system is about 50% higher than that of Bagnore 3 one.

The operation of Travale system has allowed to gather additional experience on the process as the fluid characteristics differ from these of Bagnore 3 fluid. In fact Travale plants are fed by a steam dominated field and the fluid is characterised by a very low ammonia content.

The results of Travale AMIS® system comply with the forecasted performances:

-removal efficiency of Hg and H_2S by AMIS® is 99% or higher, as in Bagnore 3;

-addition of basic chemicals is needed to keep pH of the cooling water above suitable values to avoid material corrosion;

-removal of SO_2 is very effective, nearly 100%, as a consequence of the basic chemicals addition.

Further to the positive results of Bagnore and Travale, ENEL decided to start the construction of fifteen AMIS® systems, according to a very tight schedule, in order to retrofit the major part of the existing power plants.

4. CONCLUSIONS

AMIS® is an efficient, safe, environmentally friendly technology able to eliminate the problems related to the gaseous emissions from geothermal plants and in particular the bad smell of hydrogen sulphide.

AMIS® system will be installed on all new power plants. In addition, a program has been started in order to retrofit existing power plants with AMIS®.

Fifteen AMIS® systems will be commissioned by 2006, treating about 80% of the overall gaseous emissions. The completion of this program will represent a cornerstone of the environmental upgrading of ENEL geothermal generation park.

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