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Electricity generation from NCG (non-condensable gases) expansion in Latera geothermal plant, Latium, Italy

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ABSTRACT

Aim of this paper is the presentation of an innovative project for increasing the electric power generation in Latera geothermal plant, by means of a turbine expander, recovering the pressure energy from the non-condensable gases (NCG) separated from the geothermal fluid.

The new plant is designed for a peak power of 3.6 *MW*, in addition to the 26 *MW* generated by the geothermal plant, whose commissioning is at present under way.

Latera plant is based on the NCG separation upstream from the turbine inlet, because this solution allows a higher efficiency, in comparison with other schemes, where the geothermal fluid is directly fed to the turbine.

The energy recovery, by means of a turbine expander driven by the separated NCG, will therefore give a significant increase to the overall efficiency of the plant.

The single-stage turbine expander will operate with a NCG stream at 10.5 bar abs. and 136°C at the inlet. The working fluid will **be** discharged to the atmosphere after the expansion in the turbine.

While the technology of natural gas expansion is proven, this project is aimed to demonstrate the possibility of obtaining a consistent and reliable energy generation from geothermal off-gases. The expansion of the NCG requires a tailored approach, due to the chemical and physical characteristics of the NCG.

KEYWORDS

Latera, NCG, turbine expander

1. Introduction

Latera geothermal field is located in central Italy (about 100 km Northwest of Rome), in the Monti Volsini volcanic region **of** northern Latium, west of Bolsena Lake.

The water-dominated geothermal resource is characterised by an unusually high content of NCG (non condensable gases), mainly consisting of CO_2, which have to be dealt with in order to optimise the exploitation cycle, based on flashed steam.

Thus in the original project the NCG were separated in a reboiler (a sort of pressurised direct-contact condenser) and directly sent to the cooling tower.

The availability of a high flow rate of pressurised off-gases from the reboiler, coupled with the development of the turbine expander technology **for** process gases in the last years, led to the installation of this equipment.

The present paper describes this solution **for** the recovery of the pressure energy of the NCG separated by the reboiler. Its characteristics of innovation allowed the funding of the plant by tbe Commission of the European Communities in the framework of the 1997 Thermie Program.

2. Characteristics of the geothermal resource

Latera water-dominated reservoir, mainly made **up** of carbonate and carbonate-siliceous formations of the Tuscan series, lies within a caldera of the same name and extends beyond its rim to the North-east. **A** total **of** 19 wells were drilled, some of which directionally, with depths ranging from 450 m to 3000 m.

The aquifer has temperatures in the range 190-230°C, with typical values of about 210°C. The enthalpy of the produced fluid (a two-phase mixture at wellhead) is around 900 kJ/kg, with a non-condensable gas (mainly C02) content of ***3-6%*** by weight.

The total flow of geothermal fluid (mainly water) to be produced for the operation of the power plant is around 1,500 t/h, using *5* wells located in **the** middle of the field. Reinjection will be carried out essentially in the northern part of the field.

The brine produced by the Latera reservoir is characterised by a high NCG content which, although enhancing the production rate of the wells (by gas-lifting effect), **is** a substantial drawback in the power cycle.

The result of the reservoir modelling was an expected mean NCG flow rate of around 70 t/h for at least 8 years. i.e. the average time expected for the reinjected water to reach again the production wells. The upper limit in the NCG flow evaluation was fixed at 110 t/h (SABATELLI 1987).

Further details on the geology and the geochemistry of the field can be found in the literature (BARELLI et **al.** 1983; **GIANELLI** & *SCANDIFFIO, 1989*).

3. Description of the project

For the exploitation of Latera geothermal resource, a preliminary 4.5 MW single-flash power plant was built and started in 1984 (also funded by the Commission **of** the European

Community in the framework of the Thermie Program), in order to assess the reservoir characteristics. Its operation was ended in 1987, after the completion of the test phase.

Owing to the favourable results obtained, the design and construction of a 26 MW geothermal power plant was started. This plant consists of a double flash cycle, with upstream NCG removal by means of a direct-contact reboiler (ALLEGRINI et al. 1989; SABATELLI & MANNARI 1995).

Geothermal fluid is separated at wellhead at 11 bar and 177°C; both separated water and steam (with a high NCG content) are piped from two well pads to the power plant site, where water is flashed twice (at 6.3 bar and 2.8 bar). Steam with NCG feeds the reboiler, where saturated water at 130°C and 160°C is used, respectively in the top half and in the lower half, to condensate the steam. There are two outlet streams from the reboiler, operating at 10.6 bar: the NCG are discharged from the top in saturated conditions, at a temperature of around 136°C, and the hot saturated water from the bottom, having an approach of a few degrees with the inlet steam.

This hot water is flashed twice, in dedicated vessels, at the same pressures as the water separated at wellhead, thus producing additional steam to feed the turbines. The residual flashed water is recirculated to the reboiler.

The flashed steam contains a small fraction of the NCG present in the geothermal fluid this is due to gas dissolution both in the water separated at wellhead and in the water produced by the reboiler and to the subsequent stripping in the flashers. A compressor is thus required to extract the gas from the vacuum condenser.

Discharge to the atmosphere was initially foreseen for the NCG outlet from the reboiler. The flow-scheme of this cycle, with the main process data, is given in figure 1. This scheme also shows the turbine expander for the NCG, not provided for in the initial project.

This plant consists of a new expansion line, where a single-stage turbine is fed by the NCG separated from the geothermal fluid feeding the Latera power plant.

The NCG are derived at the outlet of the reboiler from the existing line, used in the conventional plant for releasing the gas to the atmosphere through the cooling tower.

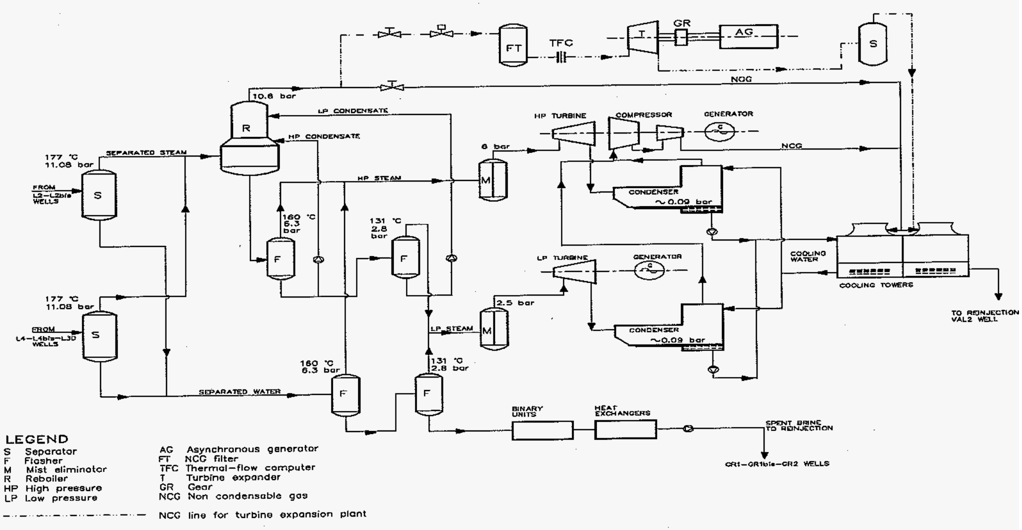
The new NCG turbine expander will drive an asynchronous generator producing a peak power of 3.6 MW. This gives a significant contribution to the capacity of the geothermal plant, increasing the overall electricity generation by 14%.

The new NCG expansion line includes a filter for the turbine protection (it is of paramount importance to separate liquid particles upstream from the turbine inlet), a computer for the calculation and monitoring of the performances and the single-stage turbine, coupled to an induction-type asynchronous generator by means of a gearbox.

The exhaust of the turbine expander will be released to the atmosphere through the cooling tower, after removal of the liquid phase produced by the expansion process in a moisture separator.

The turbine expander will be arranged in parallel with a by-pass line, in order to allow the operation of the reboiler when the turbine expander is not in operation.

A trip valve is provided at the inlet of the expansion line and will be actuated by all the trip signals coming from the control system of the expansion plant.



1: Flow scheme of the Latera power station and NCG expansion plant

In case of trouble, the expansion line will be automatically closed and the NCG discharged through the by-pass line.

Latera power plant is built to be operated unattended. Therefore, the NCG turbine expander generating set shall be able to run unattended, too. In case of operating problem and/or equipment failures, the turbine expander shall be able to make a safe emergency shut down procedure, without damage to itself or to the connected equipment.

However, attending personnel will perform on-site the start up and the shut down of the turbine expander.

4. Design of the turbine: problems, optimisations

4.1 Main technical problems encountered

Several features and aspects required a thorough analysis for this application. The major problems faced during the design phase are here under summarised:

- uncertainty on the working fluid composition and variability range;
- uncertainty on the NCG flow rate available during the field exploitation and optimisation on the turbine size;
- selection of the turbine technology.

The main features dealt with are reported in the following paragraphs.

4.2 Fluid composition

Latera power plant has not yet started its operation; therefore, the composition of the available fluid and its trend of variability were thoroughly analysed taking into consideration the existing data.

As the turbine expander is fed with NCG taken of the reboiler outlet, these will be in saturated conditions, thus including a considerable amount of water vapour, depending on the operating conditions (pressure and temperature) of the reboiler.

The expected fluid composition (NCG + water vapour), based on the available gas analyses and the reboiler operating design range, is presented m table 1.

The presence of H_2S required a careful analysis of the materials to be utilised. NACE criteria were followed for the design and cast AISI 316 stainless steel was finally selected for the turbine casing, whereas for the impeller the option between stainless steel (17-4 PH or X5 CrNi 13.4) and Inconel 718 is still pending.

The presence of hydrogen and methane in the NCG was also carefully evaluated as far as explosion proof requirements of the equipment are concerned. The area of installation of the turbine expander will not be classified as hazardous.

Table 1: Composition and variation range of the turbine expander feed gas

Component	Molar content (% v/v)	Range of variation (% v/v)
CO_2	66.73%	-3.3/+7.1
N_2	0.84%	-0.04/+0.09
H_2S	0.77%	-0.04/+0.09
CH_4	0.03%	-0.01/+0.01
Ar	0.08%	-0.01/+0.01
H_2	0.03%	-0.01/+0.01
H_2O (vapour)	31.51%	-3.4/+7.3
TOTAL	100.00%	
Molecular Weight	35.6	-0.9/+1.9

4.3 Available flow rate: optimisation of the turbine size

The available NCG flow rate will vary along the time, being affected by a reduction during the plant life, due to the effect of the exploitation of the geothermal resource.

According to the reservoir studies carried out, a minimum life of 25 years can he assumed for the geothermal resource. The NCG flow rate is expected to he around 70 t/h during the first year of operation, then steadily decreasing year by year, leading to a final value of 17 t/h during the last year.

Of course, this estimation is affected by a certain degree of uncertainty, and therefore the selection of the turbine size has been carefully studied.

The selection has been carried out modelling the system operation for 25 years, with an average flow of 73 t/h of saturated fluid in the first year (corresponding to a conservative estimation of 60 t/h of NCG) and taking into account the above mentioned flow decrease during the plant life. The operating period of the turbine expander was assumed 7,500 h/year. Turbine sizes corresponding to design flows varying from 50 t/h to 73 t/h were considered. The possibility of overloading the turbine by 50% with reference to the design flow (with a penalty in terms of isentropic efficiency, of course) allowed the turbine to manage all the flow available. Smaller turbines are affected by lower efficiencies at higher loads (i.e. during the first years); on the other hand, larger turbines have lower efficiencies at reduced loads, i.e. during the last years.

The calculation revealed that, due to the compensation of the opposite effects, the total electricity generation in 25 years is nearly the same, between 205 and 210 GWh.

A turbine expander characterised by a design flow of 73 t/h was selected, however, due to the higher generation in the first eight years, when the electricity produced from renewables receives a premium price.

4.4 Selection of the technology for the turbine-generator arrangement

Two options are at present available for commercial turbine expanders:

- "two-machines arrangement", where the turbine is coupled to the electrical generator by means of a gearbox. The generator speed is normally 3,000 or 1,500 rpm;
- "integrated construction", where the turbine directly drives the generator (thus rotating at the **same** speed of the turbine). Special solutions are necessary for the electrical plants, in order to convert the high-frequency electrical energy produced by the generator to the 50 Hz of the grid.

The former technology has been selected since the beginning **of** these applications so that it is proven, whereas the latter has been developed only recently and will probably become the leading technology in the next **future.** Up to now, several applications of the integrated construction type have been successfully operating for few years and the maximum installed power is 3 MW. As Latera turbine expander will produce over 3.5 MW, the proven "two-machines arrangement" was chosen, in order to avoid the addition of further risks to an application that is already characterised by a high degree of innovation, related to the off-gas characteristics.

As matter of fact, this technology bas been already utilised and proven in many applications for energy recovery from natural gas depressurisation in Italy (PIEMONTE 1991; PATURIAUX 1989), also in connection with a thermal power plant (e.g. Mincio power plant, where another Atlas Copco turbine generates about **4.5** MW).

5. Performances

The performances and the main features of the NCG turbine expander are shown in table 2. The modelling of the turbine operation was carried out as described under paragraph 4.3.

For the selected solution (turbine with a design flow rate of 73 **t/h),** the electrical power at design conditions is 2,840 kW. The maximum flow rate allowed by the turbine is 100 t/h; consequently, the maximum power output is 3,625 kW.

The estimated electricity generation in the fust year of operation (7,500 h with an average flow of 73 t/h) is 20,600,000 kWh. Yearly generation decreases down to 3,000,000 kWh in the 25th year (when the average flow is 17 t/h).

The cumulated electricity generation in 25 years is expected to be 207 GWh.

Condition		Maximum flow	Average flow
Flow	t/h	100	73
Molar mass	kg/kmol	37.31	38.02
Inlet pressure	bar abs	10.5	10.5
Inlet temperature	°C	136	136
Outlet pressure	bar abs	1.29	1.15
Outlet temperature	°C	73	70
Isentropic efficiency	%	80.0	82.5
Rotation speed	rpm	14,150	14,150
Electrical power	kW	3,625	2,840
Impeller diameter	cm	56	56
Flanges in/out	mm	400/750	400/750

6. Conclusions

Latera development shows that the reboiler technology makes it possible to exploit brines with a high NCG content The recovery of the pressure energy of the reboiler off-gas allows a significant increase of the power generation and of the utilisation efficiency of the extracted brine

Careful selection of the expander size, arrangement and technical characteristics are required in order to deal with this innovative application, due to the particular features of the expander feed gas

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