DEVELOPMENT IN GRAPE TECHNOLOGY FOR GEOTHERMAL PLANTS

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Abstract: The basic characteristics of GRAPE technology (standard design package for geothermal power plants) have been previously described. In this paper typical data for the present generation of plants, coming from actual tests at Bacon Manito and Gunung Salak, are reported and compared with the proposed plants.

1. INTRODUCTION

In recent papers (Lazzeri *et al.*, 1994 a,b) the authors have presented GRAPE technology for geothermal applications; the design presented a series of modifications and improvements over and above the traditional Ansaldo plants, which aimed at better performances and lesser costs. Some of these implementations were already introduced in the current generation of plants (going into operation in the early months of 1994) and the results are available and shall be discussed hereinafter. At the same time some novelties have been considered with particular reference to the cooling circuit, namely the extraction system for NCG (non condensable gases) and the type of condenser with possible consequences on the characteristics of the cooling tower.
Basically GRAPE is a family of geothermal plants with power ranging from 5 to 55 MW (110 with tandem compound arrangement) at nominal conditions. The nominal conditions are as follows :

Table 1.1
Reference data for GRAPE plants

Steam inlet pressure/temperature	6.5	bar/sat.
Exhaust pressure	0.1	bar
NCG content (weight)	1.5	%
Air wet bulb temperature	20	°C

Under these conditions the heat rate is calculated to be about **20.000** kj/kWh, depending on the NCG extraction system and the size. In particular the commonest configuration is GRAPE 55 the data of which are. as follows (in the steam ejector configuration):

Table 1.2
GRAPE 55 - Reference consumption
Steam ejector configuration

Turbine steam consumption	105.66	kg/s
Ejector steam consumption	5.06	kg/s
Steam rate (turbine)	6.916	kg/kWh
Steam rate (total)	7.247	kg/kWh

and the basic characteristics of the components are as follows:

Table 1.3
General data for components of GRAPE 55

Turbine :
- six stages impulse, double flow, 23/26" last blade, 3000/3600 rpm
- humidity extraction at four stages
- enhanced inlet valves
- sealing on rotors and stators
- enhanced gland sealing

Condenser :
- direct contact, compact type, separate stripping section for NCG

NCG Extraction :
- steam ejector (three stages with intercondenser)
- hybrid (steam ejector and liquid ring pump)
- compressor (three stages, cantilever, on turbine shaft)

Cooling tower :
- splash type counter flow

2. TEST RESULTS ON PARTIALLY IMPLEMENTED GRAPE CONFIGURATIONS

The configuration of GRAPE was partially (due to time reasons) implemented for Bacon Manito plant in the Philippines; the reference data for such plants are slightly different from the ones previously presented and are as follows :

Table 2.1
Bacon Manito station data

Steam inlet pressure/temp	6.55	bar/sat.
Exhaust pressure	0.135	bar
NCG content (weight)	2.5	%
Air wet bulb temperature	26	°C

The configuration was somewhat different from the one shown in table 1.3 as shown hereinafter.

Table 2.2
Bacon Manito configuration

Turbine :
- five stages, impulse, double flow, 23" last blade, 3600 rpm
- partial humidity extraction
- traditional inlet valves
- sealing on rotors
- traditional gland sealing

Condenser : "pipe" type

NCG extraction: centrifugal compressor (three stages, cantilever, on turbine shaft)

Cooling tower : splash type, counter flow

The basic data for the design and the test results are shown in table 2.3.

It should also be mentioned that tests have been performed in order to increase the power of the plant to about 60 MW; this result can be achieved by a slight change of the parzialization of the first stage, hence allowing a larger flow with a slight pressure increment.

Table 2.3
Bacon Manito results

	Steam Flow (kg/s)	Inlet Pres. (bar)	Power (MW)	Steam Rate (kg/kWh)
Design	116.4	6.55	55.87	7.619
Test Unitl	118.2	6.475	56.90	7.549
Test Unit2	121.2	6.298	58.10	7.529

The same application was also performed on Gunung Salak plant (Indonesia), which basically uses the reference data already presented in table 1.1; again this plant reflects a partial implementation of the most modem tecnology; the basic characteristics of the plant are listed in table 2.4.
The drawing of Fig. 1 shows a CAD-3D model of this plant, while the actual plant after erection can be seen in the picture of Fig. 2.

Table 2.4
Gunung Salak configuration

Turbine :

- six stages, impulse double flow 23" last blade, 3000 rpm
- partial humidity extraction
- traditional inlet valves
- sealing on rotors
- traditional gland sealing

Condenser : "pipe" type

NCG extraction : two-stage steam ejector

Cooling tower : splash type, cross flow

Test results of both units are compared with the design data in table 2.5.

Table 2.5
Gunung Salak results

	Steam Flow (kg/s)	Inlet Pres. (bar)	Power (MW)	Steam Rate (kg/kWh)
Design	113.44	6.5	55	7.326
Test Unitl	110.42	6.695	55.45	7.142
Test Unit2	110.46	6.615	55.61	7.146

3. CONSIDERATIONS ABOUT THE IMPROVEMENT IN GEOTHERMAL TECHNOLOGY : THE TURBINE

In comparing the performances of a steam turbine for geothermal applications, much care should also be given to the differences in inlet/outlet conditions and non-condensable gas fraction; the results should then be normalized to some reference conditions. Recently the authors made this exercise for a particular plant, the data of which are shown in table 3.1. Correction curves for conditions different from the present ones are given by Lazzeri *et al.* (1994 a,b).

Table 3.1
Reference conditions for comparison

Inlet pressure	6.0	bar
Ehaust pressure	0.1	bar
NCG content	0.6	%

Different plants both of Ansaldo production and other vendors' were compared; the actual turbine was modelled and the steam rates under the conditions of table 3.1 were compared: the following general considerations can be drawn.

Table 3.2
Steam rate comparisons under the conditions of table 3.1 (turbine only) (kg/kWh)

70s technology	7.4 - 7.6
80s technology	7.0 - 7.4
Partial implementation	7.0 - 7.2
Current technology (GRAPE)	6.8 - 7.0

The improvements introduced can be summarized as follows :

1. blade rows completed
2. humidity removal
3. improvement of sealing both on blades and at ends
4. increase in the area of the inlet valves.

Basically, however, the consumption improvenment is strongly due to the enhancement in the technology of humidity removal. Back in the early eighties Ansaldo sucessfully introduced the concept of the humidity partial bypass in order to reduce the "effective stage humidity" (Marenzi, 1994).
As it is very well know (see the paper by Craig and Cox ,1971, which in turn quotes a paper by Baumann ,1921 or the classical work 'by Traupel, 1958), the "humidity losses" are generally estimated to be the cause for a 1 % reduction of efficiency for each percent of average stage humidity. Hence particular care has been

given to the solution of this problem; the current humidity removal techniques are:

a) "after stage" humidity removal to the condenser;
b) "inter stage" rotor bypass.

It should also be noted that the data presented in tables 2 refer to a 23" last bucket, hovewer Ansaldo has been sucessfully testing a 26' last bucket. The advantages, as discussed by Lazzeri *et al.* (1994 a,b), at the typical steam turbine back pressures, are expected to be about 1 to 2 % depending on the actual back pressure (0.08 to 0.1 bar).

4. PLANT IMPROVEMENTS

Although the turbine is definitely the main contributor to the plant efficiency other components play a very important role in the efficiency assessment, basically they are :

a) the NCG removal system
b) the main condenser

The types of NCG removal system have been used and are proposed in GRAPE technology, namely :

a) steam ejectors (e.g. Gunung *Salak)*
b) liquid ring pump (e.g. one of the last proposals)
c) compressor (Bacon Manito)

In general the choice of the particular extraction system depends on the amount of NCG. Economical considerations would suggest the use of steam ejectors for fractions below one percent and of the compressor (either turbine or motor driven) above two percent, the liquid ring pump having obvious merits in between these values with strong overlaps. In the GRAPE technology with conditions as stated in table 1.1, the comparison is as shown in table **4.1.**

Table **4.1**
GRAPE reference plant

	Steam (kg/s)	Energy (kW)	Eq.Av.Energy (kW)
Steam ejectors	5.05	0	2400
Liquid ring pump	2.50	390	1590
Compressor	0	700	700

Please note that the steam ejector solutions used in GRAPE 55 features a three stages ejector with two intercondensers, the relatively sophisticated solution being fully motivated by the large decrease in overall consumption.
As an example, the two stages extraction system used in the past has a consumption about 50 % larger.
It should also be mentioned that energetically the compressor solution as shown in the Equivalent Available Energy column, is by far the most attractive one, however it is costwise the worst one and some users might consider it less reliable.

GRAPE 55 features a compact type of condenser with large advantages in terms of cost and space requirements. The mechanism of heat transfer in the drop is very important in the equipment sizing (Lazzeri *et al.*, 1994 a,b). Overall condenser efficiency in the 0.8 to 0.9 range (depending primarily on the NCG fraction) can be achieved.
Surface condensers have also been used (primarily for pollution considerations); one on the possible advantages is the use of film type cooling towers with large advantages in terms of volumes.
The use of a cooling tower with splash type filling in the case of direct contact condenser is basically due to the presence of suspended solids in the flow, which might lead otherwise to severe clogging of the cooling tower itself. On the other hand, a cooling tower with a film type filling coupled with a surface condenser would require a large amount of fresh water (roughly the same amount as the steam flow), which is not always available. The two solutions are compared in table 4.2

Table **4.2**
Condenser **solution** comparison

	Direct contact	Surface
Efficiency	0.8 - 0.9	0.7 - 0.8
Pollution control	poor	good
Cooling tower type	splash	possibly film
cost	lower	higher

5. CONCLUSIONS

GRAPE technology represents the current status of development in geothermal plants.
Basically the advantages should be found in :

a) standardization of the plant;
b) efficiency improvement.

It should also be mentioned that the authors are also active in the development of Kalina type geothermal plants; a careful analysis (Diotti, 1993) would indicate large advantages in the use of such technology combined with GRAPE plants.

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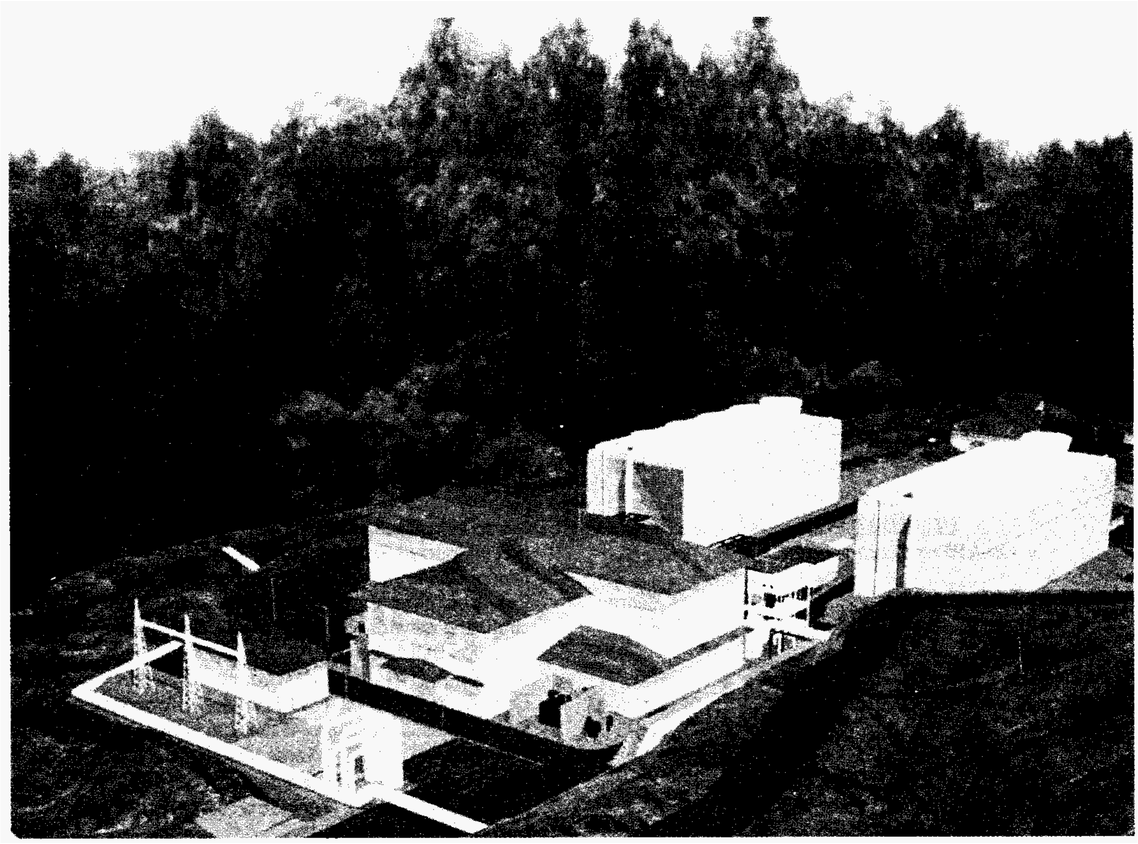

Fig. 1 - Gunung Salak (2x55 MW) : CAD model

Fig. 2 - Gunung Salak (2x55 MW) : real picture