THE DARAJAT RESOURCE: IMPLICATIONS FOR DEVELOPMENT

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SUMMARY : Extensive computer simulation of the Darajat reservoir performance, together with operational experience from the neighbouring steamfield of Kawah Kamojang, has convinced the developers, Amoseas Inc., that high reservoir pressures can be maintained for many years. Improvement in the control of exhaust steam wetness has removed one of the principal constraints to increasing turbine inlet pressure, allowing geothermal power plant and steamfield developers to enjoy the economic and thermodynamic advantages of increased system pressures.

The most significant advantages offered by the use of high pressure steam are a substantially lower steam consumption and specific steam volume leading to smaller pipelines, turbines and cooling water systems. The steam consumption of steam jet ejectors is dramatically reduced. The substantial reduction in initial capital cost will enhance the comparative advantage of geothermal generation.

1. INTRODUCTION

The Darajat resource is located in West Java on the flanks of Mt Kendang, lying in a north-south trending quaternary volcanic range containing centres of relatively recent activity. The field lies in steep and rugged terrain about 60 km south-east of Bandung, a major provincial city, as shown in Figure 1. The Kamojang geothermal field, now developed to 140 MWe capacity, is approximately 10 km to the north-east. The prominent Gagak and Cipandai faults, emphasize the dominant NE-SW structural influence in the region.

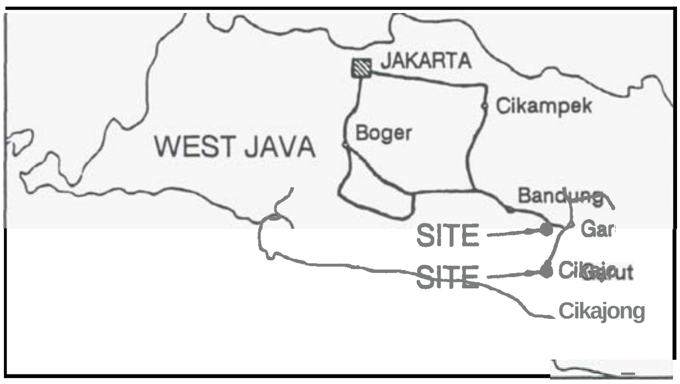

Figure 1. *Site* Location **Map**

The volcanics include andesites and basalts as well as lavas and breccia. The Darajat Kawahs (thermal manifestations) include numerous fumaroles, hot springs and boiling mud pools at an elevation around **1950** m with a natural heat flow estimated at 66 MWth.

The first well DRJ-1 was relatively cool but **DRJ-2** drilled to 760 m encountered a maximum temperature of **239°C** and produced dry steam from a reservoir pressure of **32** bar. Indications were sufficiently encouraging for Pertamina to continue the drilling programme with **DRJ-3,** drilled to a depth of **1521** m in **1978.** The well penetrated around 600 m of reservoir with a maximum temperature of 240°C and an equivalent electrical capacity of 6 MWe.

Well DRJ-4, deviated to the north-west, has penetrated the main core of the reservoir to a vertical depth of 1470 m and produces dry steam with an equivalent capacity of **11** MWe. Well DRJ-5 was drilled to the south-west from the southern side of the field and appears to have skirted the reservoir. Despite achieving a temperature of 239°C, the well was impermeable and produces only 1 kg/s of dry steam with a high gas content.

Well DRJ-6, sited between DRJ-1 and DRJ-2, was drilled to the north and appears to be outside the margin of the reservoir. No significant permeability was encountered and no stabilised temperatures were obtained. After a delay of some months, well DRJ-7 was drilled to the west from a location adjacent to DRJ-3 and encountered excellent permeability. The well discharges dry steam and has an equivalent electrical capacity of 12 MWe.

Gas contents average about **1.5%** w/w with higher gas contents obtained from the top (DRJ-2) or the margins (DRJ-5) of the reservoir. Liquid-phase geothermometers indicate reservoir temperatures of 235°C to 240°C, in close agreement with measured downhole temperatures.

1.1 Reservoir Characteristics and Resource Assessment

The Darajat field comprises a vapour dominated reservoir, similar to its near neighbour at Kamojang. The rocks of the area comprise propylitised andesites, lavas and breccias with frequent faults and fractures. Although the mobile fluid within the reservoir is steam it is conjectured (Whittome and Salveson, **1990)** that the rock matrix contains liquid water with an estimated reservoir saturation of 33%. The reservoir vertical pressure gradient is twice that for static vapour.

Together with the very extensive geophysical data, (Sudarman, **1983)** the drilling programme to date has proven a resource area of around 5 km^2. Numerical simulations have been run on Chevron Corporation's geothermal simulator using a model of over 2000 cells based on measured reservoir parameters, faults and stratigraphy. Reservoir data indicate that current downhole conditions are near to saturated steam at around **35** bar, with simulation results predicting that enthalpies are unlikely to rise above saturation at reservoir pressure. The estimated reservoir volume of 6 km^3 is believed to contain between 160 and 260 million tonnes of reservoir fluid, with sufficient capacity to supply a 55 **MWe** plant for at least **25** years. The proposed initial development of ***55*** MWe is deemed to be technically feasible.

The dry-steam production and high reservoir transmissivities provide relatively flat well output characteristic curves and shut-in wellhead pressures that approximate to reservoir conditions, see Figure 2. This means that the maximum power output is obtained at wellhead pressures approaching **15 bar** (Figure **3).** The substantially lower specific volumes and specific steam consumption at higher pressure can offer significant savings for both the steamfield and the power plant operators. Extensive reservoir simulation studies have indicated that high reservoir pressures can be maintained at Darajat over many years of exploitation. The performance of wells at the adjacent Kamojang field provides additional confirmation.

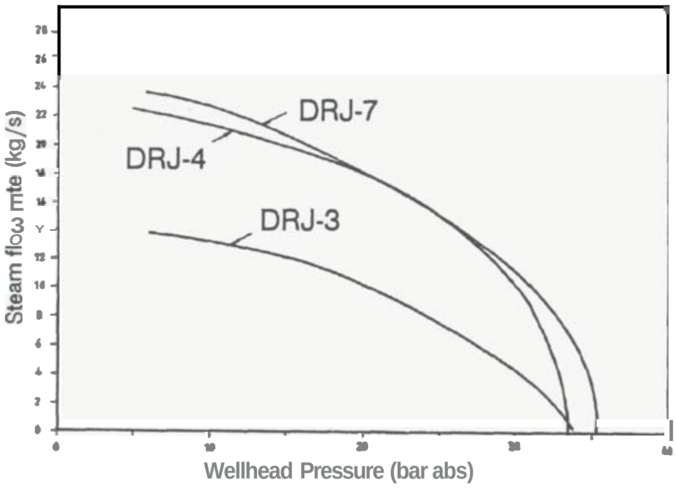

Figure 2. Well Output Characteristic Curves for Darajat Wells.

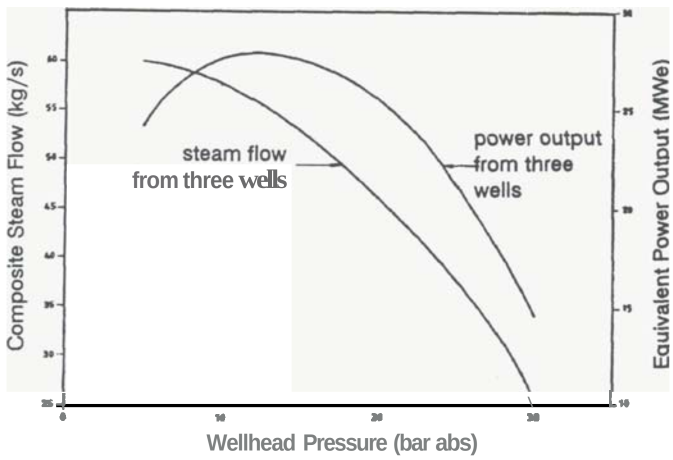

Figure 3. Composite Characteristic Curve and Power Output Curve for Darajat Wells.

2. PROJECT TECHNICAL DESCRIPTION

The proposed Darajat power plant will connect to the electrical grid supplying the whole of Java. Although the unit capacity of ***55*** MWe is small by comparison with most other units on the grid it is anticipated that the plant will operate on base-load.

Amoseas is currently planning to use the existing producing wells, together with three additional wells, to supply steam for an initial development capacity of 55 MWe. Existing drilling pads will be used to site the new wells which are likely to be completed with large diameter casings and liners.

With the opportunity to take advantage of the high reservoir pressure, the effect of a high inlet pressure on turbine exhaust wetness has been reviewed in detail, as have the technical and economic implications of reblading and derating of the turbine to accommodate a possible decline in reservoir pressure.

Experience world-wide shows that the principal contributor to geothermal turbine downtime and reduction in load factor is solids deposition within the turbine and this has been demonstrated at the neighbouring Kamojang plant. Particular attention has therefore been paid to a steamfield design that will ensure high steam quality. With the current high discharge enthalpies the proportion of dissolved solids found in the steam is very low and pipeline steam scrubbing will be sufficient to maintain a high steam quality at the turbine inlet.

It may eventually be necessary for the steam to be desuperheated to ensure adequate scrubbing of dissolved and suspended solids and possibly also for the control of fluid pH.

2.1 Development Layout

Geothermal energy is both expensive and wasteful to transport for any significant distance and geothermal steam lines of more than a few kilometres length are rare. The challenge for the Darajat area was to find an acceptable power plant location which minimised overall development costs.

The only central power plant site linking the best production wells DRJ 3, 4 and 7, was located on the ridge between DRJ-2 and DRJ-6 well pads. This site would be very limited in extent and would involve the excavation of around 70,000 m^3 of spoil.

The preferred plant site was located on a flat-topped rise, judged to be on the north-east boundary of the resource. This site was the most attractive from the site earthworks viewpoint, requiring around 25,000 m^3 of excavation, although it incurred the greatest pipeline length. It was also the site most readily extended, if required, for subsequent power plant expansion.

Pipeline access between the north and south field sectors was identified as the area of greatest cost and potential risk. The major mud-flow from the Kawah Cigupakan area in 1988 raised particular concerns over security of supply from the south-west resource sector. The pipeline crossing of the Cibeureum Stream also poses a significant geotechnical problem and will involve further investigation.

3. STEAMFIELD DESIGN

The dry-steam nature of the Darajat resource will significantly simplify many aspects of steamfield design and operation. Steamfield piping systems should comply with ANSI B31.1 Power Piping Code as well as meeting the requirements of all relevant Indonesian design codes. All piping from the wellheads to the fist operating valves should be rated for maximum reservoir conditions to avoid the need for pressure protection.

The recommended pressure rating of 18 bar (at 208°C) for pipelines will allow a sufficient margin for "blowdown" of system safety valves and for any increase in pressure to offset decline in turbine output due to solids deposition.

Substantial cost savings are possible if the whole steamfield system can be designed to operate at high pressure. In addition to the lower specific steam consumption, the significantly lower specific steam volume at a system pressure of 15 bar would result in only half of the volumetric flow rate compared to a pressure of 6 bar. The smaller pipeline diameters result in a simpler design with greater inherent flexibility and less cumbersome expansion compensation. The smaller anchor and support sizes, with consequently shorter installation times, will also contribute to substantially reduced steamfield costs.

3.1 Thermal Expansion and Pipeline Support

Thermal expansion of the pipelines may be partly compensated by natural flexibility of the pipelines traversing the natural topography. Additional compensation will be required, however, and a detailed site-specific design study will be required to select between compensator loops or bellows compensators.

Pipeline support will involve a sequence of anchors, sliding supports and pipeline guides at regular intervals. Support spacing is governed by the need to ensure that the natural frequency of pipe oscillation is well above the anticipated seismic frequency response.

Vertical wellhead movement due to casing expansion will require counterbalance or spring-type supports for the pipelines adjacent to the wellhead. Counterbalance supports are simpler to design and maintain, and offer greater flexibility in the face of likely wellhead vertical movements of up to 300 mm.

Much of the pipeline length will be on sloping ground, adjacent to existing roading and fill materials, and piled foundations are recommended. Foundations would consist of 400 mm diameter piles of cast-in-situ reinforced concrete to a depth of around 3 m.

3.2 Steamfield Control System

The large steamline volume ensures a high system capacitance and pressure transients caused by load fluctuations will therefore be relatively slow. The control system will require a wellhead throttling system on selected larger wells to maintain a steady header pressure by matching steam production rates to power plant demand.

A steam venting system reasonably close to the power plant will control steam conditions at the contract interface to within specified limits. Steam venting should be required only during transient operating conditions.

4. THE POWER PLANT

The preliminary design parameters for the power plant have been based on current reservoir and well output information and are as follows:

Turbine gross output	55 MWe
Generator capacity	55 MWe at 0.8 PF (68750 kVA)
Inlet pressure range	10 - 15 bar abs
Condenser pressure	0.1 - 0.15 bar abs
System frequency	50 Hz
Turbine speed	3000 rpm
Non-condensable gas content in steam	1.5% by weight

A site layout has been developed to minimize piping costs and for appropriate positioning of electrical switchyard and off-take structures. Cooling towers have been located for optimum exposure to the prevailing winds while avoiding spray crossing the power plant and switchyard.

4.1 Civil and Structural

Being in an active seismic zone, the structure should be designed to remain functional after an earthquake of 500 year return period, with a basic coefficient for short period structures of 0.08g. Structural detailing based on the relevant New Zealand seismic codes is proposed as they are among the most developed in the world.

Foundation conditions are suitable for power plant support although major plant items sensitive to differential settlement would be established on an extensive concrete raft foundation.

4.2 Mechanical Plant

The principal items of mechanical plant include the turbine, condenser, hot well pumps, cooling towers and gas extraction equipment. The turbo-alternator comprises the single most costly item and the key parameters determining cost and performance are gross power output and the inlet and exhaust pressures.

Steam Inlet and Exhaust Pressures

An increase in turbine inlet pressure leads to an increase in the energy available in the steam to do useful work and the specific steam consumption is reduced. In addition, the reduction in steam specific volume at higher pressures further reduces the size of valves and piping for the total development and leads to a substantially lower installed cost than a lower pressure system of the same capacity.

Selection of turbine exhaust pressure is largely determined by local climatic factors although particular attention must be paid to the effects of turbine inlet and exhaust conditions on turbine blade erosion, optimisation of cooling system design and the parasitic power demands such as cooling water pumps, cooling tower fans, and steam consumption by steam jet ejectors.

Extensive analysis and optimisation is necessary before the turbine inlet and exhaust pressures and temperatures can be finalized. The opthisation exercise requires technical, capital cost and operating cost data, input from the steamfield (reservoir conditions, response to exploitation, drilling and development costs) as well as consideration of the entire power plant process.

Inlet Pressure and Exhaust Wetness

A higher turbine inlet pressure increases the steam wetness at the turbine exhaust, leading to increased erosion of the turbine blades. Major developments in this area have allowed designers and manufacturers to produce turbines capable of operating at substantially higher wetness than the 10% to 12% which had previously been accepted.

An "Erosion Rate Index" has been developed by turbine suppliers (Mitsubishi, 1988) which assesses the effects on erosion rate of water droplet relative velocity, steam wetness and density, mass flow rate, blade capture ratio and wetted surface.

Assuming saturated steam conditions at a steam inlet pressure of 13 bar, an exhaust wetness of 16.3% could be expected, see Table 1. While this steam is wetter that most geothermal installations, the operation of the Java electrical system at 50 Hz means that the tip speed of turbine blading is less than that of many similar geothermal turbines and an acceptable "Erosion Rate Index" for the blading can be achieved.

Steam Quality

Turbine suppliers typically require inlet steam to contain less than 5 parts per million total solids. The condensed steam samples from the Darajat well DRJ-3, DRJ-4 and DRJ-7 have total dissolved solids contents ranging from 10 to 50 ppm, demonstrating the importance of maintaining saturated conditions during steam transmission for the purpose of steam scrubbing.

By careful design of the steamfield piping system, steam of adequate quality can be provided to ensure the long term continuous operation of the power plant. When selecting the turbine design, however, attention should also be paid to the configuration of the first stage nozzle boxes. Impulse blading tends to demonstrate larger reductions in power output for a given deposition thickness than a unit having a reaction component in the first stage blading due to the larger flow passages inherent in reaction blading design. Impulse blading on the early stages, however, ensures that deposition occurs only on the stationary nozzles rather than on the rotating blades, thereby minimizing the risk of corrosion fatigue and stress corrosion cracking. These aspects will warrant further study and discussion with turbine designers at the plant design stage.

Table 1 Effect of Turbine Inlet Pressure on Turbine Operating Parameters, NCG 1.5% by weight, with steam jet ejectors.

Turbine Inlet Pressure (bar)	6	10	13	15
Net specific steam consumption (kg/MW-s)	2.03	1.7%	1.74	1.67
Gross specific steam consumption (kg/MW-s)	2.20	1.94	1.85	1.77
Total steam demand (kg/s)	121	107	102	97
Exhaust wetness (%)	13.6	15.3	16.3	16.8

Non-Condensable Gas Extraction

Non-Condensable Gases will be extracted by steam jet ejector or by mechanical compressor. A steam jet ejector system is relatively simple and inexpensive with no moving parts, but consumes a large quantity of steam.

Rotary compressors, by comparison are expensive units and are effective only within a quite narrow operating range. Because of their lower energy consumption rotary compressors are mandatory on fields with a high non-condensable gas content and are sometimes direct-coupled to the main turbine shaft.

Steam ejectors offer fast recovery of condenser vacuum should gas compressors lose stability or trip for other reasons. They are also necessary to provide rapid establishment of condenser vacuum during plant start up. For the Darajat field, where it appears high steam pressures can be sustained and where non-condensable gas content may be expected to fall with exploitation, it is possible that economic analysis may favour the installation of steam jet ejectors only.

4.3 Retro-fitting for Lower Pressure

Should steamfield operating pressures decline to the point where continued operation at the initial pressure is no longer possible, the turbine may be retro-fitted to operate at a lower pressure. In the example investigated, for a revised pressure of 7 bar, retro-fitting is appropriate and would involve:

(a) Decreasing the number of stages in the turbine from 6 x 2 flow to 5 x 2 flow, by removal of the first stage blading and nozzles, because of the smaller heat drop in the turbine.

(b) Changing the nozzle and blade configuration in the second and third stages.

With the reduction in pressure, and the consequent increase in the steam specific volume, the volumetric flow rate to each turbine would increase from 14.2 m^3/s for operation at 13 bar to 31.6 m^3/s at 7 bar. Additional piping would be required within the steamfield to transmit the larger steam mass and volume flow to the station and larger governor and main stop valves would also be required. Pre-investment in order to accommodate a later pressure reduction is likely to involve little more than the provision of sufficient room around the unit for increased piping diameters.

The required increase in steam consumption caused by a steam inlet pressure decrease would cause the heat load on the condenser to increase and would require an increase in cooling water flow of nearly 30% to maintain the same condenser conditions. An increase in pump power demand of around 270 kW would be required.

The increase in cooling water flow required for the condenser would also result in an increased requirement for cooling tower capacity of similar proportion. It is estimated that the additional cooling tower fan power could be 300 kW.

The effect on the steam jet ejector system would be two-fold. The reduced pressure would increase gas flow to the turbine by 12% (0.17 kg/s) and the reduction in steam ejector motive pressure would reduce ejector capacity by approximately 54%. These effects might be offset, however, by a reduction in the non-condensable gas content of the steam as a result of exploitation.

At a turbine inlet pressure of 13 bar the steam jet ejector demand is approximately half that at 7 bar.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Amoseas Indonesia Incorporated (1989): Darajat Geothermal Project Feasibility Report, Part III - Engineering.

Mitsubishi Heavy Industries (1988): Pers comm.

Sudarman, S. (1983): Geological studies of the Kamojang and Darajat Geothermal fields (Java), University of Auckland, N. Z. MSc. Thesis.

Whittome A.J. and J.O. Salveson (1990): Exploration and Evaluation of the Darajat Geothermal Field, West Java, Indonesia, GRC Symposium, Hawaii.