Proceedings 18th NZ Geothermal Workshop 1996

BENEFITS OF ADOPTING HIGH STEAM SUPPLY PRESSURE

T.D. MILLS

Geothermal Energy New Zealand Ltd., Auckland, NZ

SUMMARY - A method is outlined that permits the capital cost implications of alternative steam supply pressures to be quantified, without detailed design and price estimation being necessary. Separate savings or additional costs are evaluated for the steamfield and power plant parts of the project. The method considers the size or rating of a plant item or subsystem and determines the change in size or rating for a change in steam supply pressure. Cost changes are assessed from the estimated cost of the plant item or subsystem using normal rules for the cost of size changes. The method is applied to a comparison of existing and future units at Kamojang geothermal field, West Java, Indonesia. Appreciable cost savings are predicted for **10** bara turbine inlet pressure compared to the existing value of 6.5 bara. These apply to both the steamfield and the power plant developments. In addition, for any given electrical output, the steam withdrawal rate is expected to be about **10%** less for the **10** bara case, but the value of this has not been quantified in monetary terms.

1.0 INTRODUCTION

This paper quantifies the expected capital costs and benefits which arise in selecting the steam supply pressure for a geothermal power plant. The methodology outlined is regarded as generally applicable, and is thus as important as the particular results that are derived. The particular power plant considered comprises two future units of **30** MW size at Kamojang geothermal field in West Java, Indonesia; these units are likely to be developed by a private group. A turbine inlet pressure (TIP) of **10** bars absolute (bara) is compared to a lower TIP value of 6.5 bara.

The steam supply pressure for the three existing units at Kamojang is 6.5 bara. These units were installed in **1983** (one unit of 30 MW) and in **1987** (two units of 55 MW).

There has been some decline in the steam flow from the Kamojang wells, due to general drawdown in response to steam extraction. In the northern parts of the drilled reservoir, some wells have shown appreciable decline in well-head pressure. However, there are only a few such wells, and most wells, and all of the good production wells, actually show relatively small pressure decline.

There are a number of wells that have high well-head pressures, and these are fitted with orifice plates to reduce the pressure of the steam flow. Such throttling reduces the maximum potential energy of the wells (loss of available work); for the particular flows, the pressure drop across the orifice could be utilised in a (high pressure) turbine to produce useful power. A compromise approach for the new units may be to adopt a higher TIP value than the existing units.

A TIP value of 10 bara was adopted for Darajat, following detailed optimisation studies. Darajat is a steam dominated resource similar to Kamojang. These factors may provide a guide to TIP selection for future Kamojang units, and prompted the comparison between 6.5 bara and **10** bara TIP values.

2.0 METHODOLOGY

Capital cost estimates were made of both the steamfield development and the power plant. These estimates were prepared prior to detailed design being done, so they generally considered suitable and appropriate types and sizes of plant for steam supply pressure of between about **7** to **10** bara (TIP). Full details of the cost estimates are not provided in this paper for reasons of commercial confidentiality.

The approach used was to consider the effect of variations in TIP on particular plant items or subsystems. A size or rating can be explicitly calculated for a given plant item or subsystem, and a new size or rating can be derived for the changed TIP. The expected saving or extra cost for that particular item or subsystem is then determined from the change in size or rating using normal rules for changes in size or rating. The separate effects for plant items and subsystems are then combined to determine a balance of cost and savings effects.

The methodology is applied and demonstrated in later sections.

3.0 STEAM USAGE

The performance of a turbine generator can be estimated relatively easily, and this was done for TIP values of **10** bara and **6.5** bara. Key assumptions are turbine isentropic efficiency of **86%,** mechanical losses of 2.5%, electrical conversion of nett mechanical power at **97.5%** efficiency, and condenser pressure of 0.1 bara.

Gas content was ignored for the sake of simplicity. No allowance was made for steam supply to steam jet ejectors; but for higher TIP less steam will be used by an ejector for a given gas flow because the motive steam is at higher pressure. Furthermore, the gas flow will be lower due to lower specific steam consumption by the turbine. A hybrid system such as first stage ejector with second stage liquid ring vacuum pump could be adopted, but this would require detailed analysis. (Such analysis was done for a proposed 67 MW plant at Kamojang, and the hybrid system was favoured, GENZL (1991).) The condenser heat load can also be calculated from the turbine performance, and used to assess size and cost of the major plant items within the cooling system.

The estimated rates for steam usage and mass flow for the two turbines (60 MW combined rating) are summarised in Table 1:

Table 1 - Steam Usage, Mass Flow, and Heat Load.

TIP / bara	Steam Usage / t/h/MW	Steam Mass Flow / t/h	Condenser Heat Load / MW_{th}
10	6.35	381.1	115.5
6.5	**6.99**	**419.5**	**129.4**

4.0 IMPLICATIONS FOR STEAM FIELD

The selection of steam pressure is expected to impact on several aspects of the steamfield design, as discussed below.

4.1 Number of Wells

The average well output curve for Kamojang (transposed to turbine inlet) is known from earlier evaluations of the 67 MW project, GENZL (1991), and is shown in Figure 1.

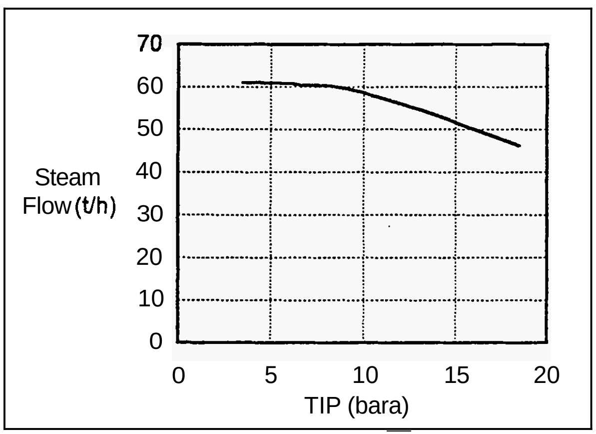

Figure 1 - Average Well Output Curve (at Turbine).

From this information, the number of wells required for the 60 MW project (2 x 30 MW units) can be estimated for each TIP, and these are shown in Table 2.

TIP / bara	Average Well Flow / t/h	Exact Well Numbers	Whole Wells and MW Output
10	58.5	6.5	7 ≡ 65 MW
6.5	60.6	6.9	8 ≡ 69 MW
insufficient steam capacity with 7 wells			7 ≡ 61 MW

One extra well is required for 6.5 bara TIP, compared to 10 bara. The cost of a well is estimated to be USD 2,250,000.

It should be noted (from Table 1) that the total mass withdrawn from the field would be increased by 10% for 6.5 bara TIP compared to 10 bara; the resource would decline more rapidly due to the higher mass extracted.

Selecting eight production wells for the 6.5 bara case would give greater spare steam supply capacity, therefore delaying the first make-up well, but more make-up wells would be required over the life of the project, probably outweighing any delay in the need for the initial make-up well.

4.2 Cost of Pipelines

Pipeline Diameter- The size of pipelines would be reduced for 10 bara TIP compared to 6.5 bara.

A simple approach by which to determine the size reduction is to assume a fixed steam velocity. The cross sectional area of pipe would then be proportional to the volumetric flow of steam, and the resulting diameter ratios (square root of area ratio) are shown in Table 3.

Table 3 - Steam Flows and Diameter Ratio.

TIP / bara	Steam Flow / t/h	Steam Flow / m^3/s	Diameter Ratio
10	381.1	20.58	77% [= $(20.58/34.28)^{½}$]
6.5	419.5	34.28	100%

Strictly speaking this analysis should be made for some value of pressure between the well-head pressure(s) and the TIP, but similar ratios would be derived. This indicates that the pipe size is reduced to about 80% of the size for the 6.5 bara case.

Another basis for estimating the pipe sizing is to allow for the same pressure gradient in the pipelines for the 10 bara and 6.5 bara cases. The pressure gradient is given by the expression

$$\delta P/\delta L = 32.f.m^2.\rho^{-1}.\pi^{-2}.D^{-5} \quad (1)$$

or, assuming constant Moody friction factor of 0.003,

$$\delta P/\delta L \approx 0.01.m^2.\rho^{-1}.D^{-5} \quad (2)$$

The requirement for the same pressure gradient thus results in a relationship

$$\{m^2.\rho^{-1}.D^{-5}\}_{6.5\ bara} = \{m^2.\rho^{-1}.D^{-5}\}_{10\ bara} \quad (3)$$

or

$$D_{10}/D_{6.5} = [m^2_{10}/m^2_{6.5}.\rho_{6.5}/\rho_{10}]^{0.2} \quad (4)$$

or, using the pressure ratio for the density ratio,

$$D_{10}/D_{6.5} = [m^2_{10}/m^2_{6.5}.6.5/10]^{0.2} \quad (5)$$

The resulting diameter ratios are shown in Table 4.

Table 4 - Steam Flow and Diameter Ratio.

TIP / bara	Steam Flow / t/h	Diameter Ratio
10	381.1	88% [= $^{0.2}\sqrt{\{381^2/420^2.(6.5/10)\}}$]
6.5	**419.5**	**100%**

As already noted, this type of evaluation should be made for some middle pressure value between the well-head(s) and the turbine, but similar ratios will result. This suggests the pipe size is reduced to about 90% of the size required for 6.5 bara case, for the requirement of equal or fixed pressure gradient. This is regarded as a more realistic approach than simply assuming constant steam velocity.

Pipe Wall Thickness- An increase in wall thickness might be expected due to differences in pressure, and design pressures of 10 barg and 15 barg were assumed for the two TIP values. Wall thickness would be determined by the applicable corrosion allowance, and the calculation of wall thickness as a function of pressure and diameter (hoop stress calculation).

To determine the relative effects of increasing pressure and reducing diameter, a diameter corresponding to half of the total flow was selected as the basis for the wall thickness calculation, and diameters of 26" and 30 were determined. Details of the required pipe wall thickness are summarised in Table 5:

Table 5 - Required Pipe Wall Thickness.

TIP / bara	Pipe Dia. / mm (")	Wall thickness / mm (incl. 3 mm corrosion allowance)
10	660 (26)	8.2 mm
6.5	762 (30)	7.0 mm

For 30" pipe size, Schedule 10 pipe, which has a wall thickness of 7.92 mm, is (just) inadequate at the -12½% tolerance level, and standard weight pipe (wall thickness 9.53 mm) would probably be specified. For 26" pipe, standard weight pipe would be required (wall thickness of 9.53 mm equates to 8.34 mm at the -12½% tolerance level).

As noted above, the thickness calculation assumes hoop stress is the only factor affecting the selection, and other considerations may also have a bearing. These include the piping layout to be adopted, and the practical choices that would be made within a particular class of fittings (e.g. Class 150) where the pipe weight would be matched to the rating of the fittings.

It is thus generally expected that the reduction in pipe diameter should largely offset the increase in pressure, resulting in little effect on the weight of pipe specified. Since other factors can have a bearing, the effect of increased pressure on the pipe wall thickness has been neglected.

Cost of Pipelines- Calculations can be made to derive (the sum of) pipeline Diameter-Inch-Foot (DIF) values for each TIP case. (Further to the above comments on pipe wall thickness, costs derived on the DIF basis take no account of pipe wall thickness. This is because the material cost of the pipe is only one component of the installed cost of pipelines.)

The overall impact on the pipelines is to reduce the DIF value by 10%. This has a saving value of about USD 900,000, assuming a cost of pipelines of USD 9,000,000.

This figure is conservative as it ignores the fact that one less well needs to be connected. The cost of connecting a single well is taken as USD 500,000.

4.3 Steamfield Balance

The overall implications for the steamfield of using 10 bara TIP are:

One less well, drilling cost saving USD 2,250,000;

Reduced pipeline diameter, saving USD 900,000;

One less well needs to be connected, saving USD 500,000;

Reduced mass extraction rate - 10% less than 6.5 bara, for which a monetary value is not stated.

The total saving in capital cost is thus about USD 3.7 million, excluding any benefits from reduced mass extraction.

5.0 IMPLICATIONS FOR POWER PLANT

The selection of steam pressure affects many power plant systems, as discussed below. The cost estimates for the various systems and subsystems apply for the two 30 MW units; they are intended to be indicative only, having been were prepared prior to detailed design being done, and the data is subject to commercial confidentiality.

5.1 Size *of* Steam Piping

Steam supply piping within the power plant scope of supply (including main steam supply, demister, auxiliary steam, etc.) is assumed to be affected as for the steamfield; that is cost reduced by 10%. An assumed capital value of USD 2,000,000 equates to a saving, for 10 bara TIP, of USD 200,000.

5.2 Turbine Casing Pressure Rating

The impact of inlet pressure on turbine cost is not certain, but for manufacturers who use a standard design, the extra cost may be neglected, Saito (1995), Yamada (1995). Also, the construction of the turbine casing may comprise separate HP and LP casings, so the effect may only be applicable to an HP casing.

5.3 Condenser Sizing

Condenser heat load is significantly reduced for 10 bara TIP, principally because of the reduced steam mass flow, but the exhaust enthalpy is also marginally lower for 10 bara TIP. The heat load on the condenser is adjusted by the ratio 115.5/129.4 (refer to Table 1). The size of the condenser is assumed to be reduced pro-rata, and the cost reduced accordingly to the usual two-thirds power law. The resultant cost is estimated to be 93% of the value for 6.5 bara. Assuming a capital cost of USD 5.75 million, this results in a saving of about USD 420,000. The savings for the gas extraction system are assumed to be included in this estimate.

The effect on steam condensate disposal system is assumed to be negligible; the steam flow is reduced 10%, but heat load is down 11%, so the condensate flow is expected to be little affected by the TIP value.

5.4 Cooling **Tower**

The cooling tower also has a correspondingly lower heat load, and the size is assumed to be reduced pro-rata and costs reduced according to two-thirds power; savings of USD **420,000** are estimated, based on a capital cost of USD 5.75 million.

5.5 Main Cooling Water System

Piping- The size of cooling water lines can be reduced because the cooling water flow (heat load) is reduced by 11%, and if the size is assumed to be reduced as the square root of the flow, the costs reduce similarly resulting in savings of USD 170,000 are estimated, based on capital cost of USD 3 million.

Pumps- The size of main cooling water (MCW) pumps/motors can also be reduced because the cooling water flow is reduced (by 11%); size is assumed to be reduced pro-rata and cost reduced by two-thirds power law; cost savings of USD **200,000** are estimated, based on capital cost of USD 2.75 million.

5.6 Auxiliary **Power** Loads

The power demand for cooling tower fans and MCW pumps is assumed to be reduced by 11% (in relation to the heat load reduction). This will result in a power saving of about 130 kW, assuming the basic plant uses a total of 1200 kW for MCW pumps and cooling tower fans. This power saving can be capitalised; for a power price of 7.5 c/kWh, and assuming 80% capacity factor, the annual advantage is about USD 70,000. The capitalised value is taken as USD **450,000.**

5.7 **Other** Factors

The above effects are considered to be the main factors affecting the cost of the power plant. Electrical and civil costs (except for the cooling tower) are assumed to be unaffected by the turbine inlet pressure.

5.8 Power Plant Balance

Summarising, the steam supply pressure (TIP) impacts on the power plant, for 10 bara compared to 6.5 bara, are as follow:

Steam supply piping, saving USD **200,000;**

Condenser and gas extraction, saving of USD **420,000;**

Cooling tower, saving of USD **420,000;**

MCW and Aux. CW piping, savings USD 170,000;

MCW pumps/motors, saving USD **200,000;**

Capitalised value of reduced parasitic power demand, USD 450,000.

The combined effect on the power plant of adopting higher TIP of 10 bara (compared to 6.5 bara) is thus estimated to be about USD 1.85 million, or a little short of USD **2** million.

6.0 CONCLUSIONS

Adopting a high steam supply pressure of 10 bara at the turbine inlet is expected to decrease the cost of both the steamfield and power plant parts of the project compared to the case of 6.5 bara TIP.

The difference in steamfield capital cost may be about USD 3.7 million, due to an extra well being needed (both drilling cost and connection cost) for the lower pressure, and larger steam mains sizes would also be required.

Of importance is the fact that a lower mass extraction rate is needed for 10 bara case, some 10% less than for 6.5 bara case.

The difference in power plant costs may be nearly USD **2** million, which includes the capitalised value of reduced auxiliary power usage for 10 bara TIP. Major cost savings, all favouring 10 bara TIP, occur for the condensing and gas extraction system, the cooling systems, including the cooling tower, and various piping subsystems.

A steam supply pressure of 10 bara is thus preferred for both the steamfield and the power plant. The total cost advantage in favour of a TIP value of 10 bara appears to be in excess of USD 5 million, compared to 6.5 bara TIP.

These conclusions were derived using the stated methodology, and the results depend on the validity of that methodology. As opposed to making a detailed evaluation of all facets of the project, the methodology evaluated the cost changes in components of the steamfield and power plant developments that would be expected to be significantly affected by the selection of steam supply pressure.

7.0 REFERENCES

GENZL (1991), Kamojang Geothermal Power Plant Unit 4 - Engineering Feasibility Study, Final Report, Vol. 1. Report for PLN, Indonesia.

Saito, S. (1995), of Mitsubishi Heavy Industries, personal communication.

Yamada, S. (1995), of Fuji Electric Co, personal communication.