PB POWER

POIHIPI ROAD POWER STATION

Energy and Efficiency Audit

CONFIDENTIAL

Prepared for

CONTACT ENERGY

PB Power *Quality System:*

Document Reference	:	Morris, G.L., 2001.pdf
Report Revision	:	2
Report Status	:	Final
Prepared by	:	G L Morris
Reviewed by	:	C W Taylor
Approved by	:	Name
Date Created	:	16 July 2001
Date Issued	:	17 July 2001

TABLE OF CONTENTS

SECTIONS

EXECUTIVE SUMMARY

The Poihipi Road Geothermal Power Station was commissioned in mid 1997. Contact Energy acquired the generation assets and associated resource consents in 2000.

This report has been prepared as a companion to an energy and efficiency audit completed for the Wairakei Geothermal Power Station in June 2000. To ensure consistency between the two studies, care has been taken to apply consistent assumptions and to use a common baseline. Heat and exergy have been assessed relative to a common ambient temperature condition of 20 ^{o}C .

The report is a snapshot of the plant's operation on 16 June 2001, while operating in its typical daytime operating mode. Under the conditions of its current resource consents the plant operates at about 35 MW for the daytime period, then reducing to low load overnight.

The Poihipi Road Power Plant was developed on the southern fringe of the Wairakei resource. Original intentions for the development were to access geothermal fluid from both the upper steam zone, and from a deeper liquid dominated zone, and the resource consents reflected this intent. Poor productivity of the deep wells that were drilled led to the project being developed based on the steam zone only. The plant operates on fluid drawn from four shallow wells accessing the steam zone. The steamfield is simple in operation, with the four production wells delivering steam via a single 1.5 km main to the power station. There is no need to separate water from steam as is necessary for the Wairakei Power Station. One reinjection well is required to discharge quantities of condensate from the station back underground.

The Poihipi Road Power Station consists of a single condensing steam turbine with cooling water circulated through a mechanical draft, wet cooling tower. The generating plant is of Japanese (Fuji) manufacture and represents modern geothermal generating practice.

All data for this report has been obtained directly from Contact Energy. Poihipi is a modern geothermal power plant and data was available from the computer-based data acquisition system. While there are some uncertainties in the measurements, sufficient alternative data or means of calculation were available to mitigate such uncertainties.

The power production from the plant was 32.7 MWe net during PB Power's visit in June 2001, and the following table summarises the mass, energy and exergy flows at that time.

	Mass (t/h)	Energy, rel to 20^{0}C (MW)	Energy, rel to 20^{0}C (MW)
Withdrawn from Reservoir	270	200	57.1
Reinjected into Reservoir	124	0.02	0.02
Cooling Tower Discharge to Air	144	164	22.2
Gas and Trap discharges	2	0.7	0

Utilisation efficiency has been able to be determined. The appropriate efficiency (based on exergy) which assesses the performance of the plant against the theoretically available work has been calculated to be 57%. This level of performance is a function of the modern plant design and the supply of steam from dry steam wells.

Two scenarios were developed to investigate the effects of loading the Poihipi Road station to 55MWe with steam from the Wairakei steamfield. This involves sourcing a percentage of the steam supplied to Poihipi from steam sourced from two phase fluid with an enthalpy of 1150 kJ/kg from the Wairakei steamfield. Based on a 44/56 split of steam from Poihipi and Wairakei the utilisation efficiency was calculated as 39%, reducing to 32% if all steam is sourced from Wairakei. The reduction in utilisation efficiency reflects the extra energy carried in the separated water, and the increased parasitic load of the reinjection pumps.

1. INTRODUCTION

The Poihipi Road Geothermal Power Station was commissioned in mid 1997. Contact Energy acquired the generation assets and associated resource consent rights in 2000.

This report has been prepared as a companion to an energy and efficiency audit completed for the nearby Wairakei geothermal power station in June 2000 (PB Power 2000). To ensure consistency between the two studies, consistent assumptions and a common baseline have been applied. Heat and exergy have been assessed relative to an ambient temperature condition of 20 ^{o}C.

This report audits the Poihipi Road steamfield and the power station. The report focuses on the flows of mass, energy and exergy through the steamfield and power plant.

A PB Power engineer visited the Poihipi Road Geothermal Power Plant facility on 15 June 2001 to obtain data and to discuss details of operation with site staff. The results of this data collection and the subsequent analysis form the basis of this report.

The report is a snapshot of the plant's operation on 16 June 2001, while operating in its typical daytime operating mode operating at about 35MWe. In addition to examining plant operation as seen in June 2001, two scenarios have been investigated:

Scenario #1: Additional steam provided from the Wairakei steamfield area to load the Poihipi plant to 55MWe.

Scenario #2: All steam supplied from the Wairakei steamfield.

Performance will vary slightly from this "snapshot" presentation under different conditions such as varying station load, different air temperatures, different wellhead pressures, condenser leakage, etc.

The winter heat load observed during June will be different from the expected summer heat load. The winter performance is expected to be better than summer performance, in terms of utilisation efficiency.

2. DESCRIPTION OF STEAMFIELD AND STATION

2.1 STEAMFIELD

The Wairakei geothermal resource is located about 8km NE of Taupo. It is spread over an area of about 15km^2.

The Poihipi Road Power Plant was developed on the southern fringe of the Wairakei resource. Original intentions were to access geothermal fluid from both the upper steam zone, and from a deeper liquid dominated zone, and the resource consents reflected this intent. Poor productivity of the deep wells that were drilled led to the project being developed based on the steam zone only.

The plant operates on fluid drawn from four shallow wells accessing the steam zone. The steamfield is simple in operation, with the four production wells delivering steam via a single 1.5 km main to the power station. There is no requirement to separate water from steam, as at the Wairakei steamfield. One reinjection well is required to discharge the minor quantities of condensate from the station back underground.

2.2 STATION

The Poihipi Road Power Station consists of a single condensing steam turbine with cooling water circulated through a mechanical draft, wet cooling tower. The generating plant is of Japanese (Fuji) manufacture and represents modern geothermal generating practice.

The turbine generator is rated at 55MWe gross capacity, the terms of the resource consent for the Poihipi facility constrain its operation on a daily basis. Since commissioning, the plant has operated a 2 shift generation pattern, where generation runs at about 35MWe for 14 hours during the peak daytime demand period, then drops to about 3MWe overnight.

The Power Station has a number of auxiliary systems, using electric power, steam and cooling water. In terms of this audit, only the gas extraction system has any measurable flow that is discharged separately from the condensate. All other auxiliary systems have been grouped together to appear as parasitic electrical load requirements.

3. SOURCE AND QUALITY OF DATA

All data for this report has been obtained directly from Contact Energy. Poihipi is a modern geothermal power plant and data was available from computer-based data acquisition systems.

Data obtained by remote interrogation of gauges is of good operational accuracy (<±10%). The metering of the net exported electrical generation has a very high accuracy of <± 0.2%.

In the steamfield each well is monitored for pressure, flow and valve opening. The combined flow of the four production wells is measured at a single venturi flow meter immediately before entering the station. Generally good agreement was found between the venturi flow measurement and the summation of individual well flows (error of 4% or less). However, the venturi is considered a more reliable and accurate indicator of total steam flow than a summation of four separate annubar flow meters at the wells. Therefore for this energy audit, the steamflow measured by the venturi was taken as the prime flow measurement. The steamflow from the wellheads was derived taking account of minor losses to the steam traps and vent station between the wells and the power plant.

Sufficient data was available from the station data acquisition system to complete the audit without requiring additional manually recorded information. Access to data in this form enables a real-time determination of plant performance.

4. SYSTEM MASS, ENERGY AND EXERGY FLOWS

Data was logged for a two week period in mid June 2001 when the plant was operating in a 2 shift pattern of approximately 35MWe during the day, and about 3MWe overnight.

The data was analysed and the mass, energy and exergy flow results are shown in Figures 4.1, 4.2 and 4.3. The widths of the flow streams in the figures are approximately to scale. The calculated numbers are shown for each flow stream.

4.1 DISCUSSION OF MASS

During daytime generation at levels of 35 MWe, the fluid take is of the order of 270 t/h.

There is negligible loss of fluid between the steamfield and station in the course of normal operation, as shown in Figure 4.1.

The Poihipi condenser is a surface condenser constructed with tubes so that the cooling water and exhaust steam from the turbine do not make direct contact. Once the condensate is extracted from the condenser it is mixed into the cooling water stream and passed to the cooling tower. As Figure 4.1 shows, approximately 53.4% of the incoming steam to the station is dispersed in the cooling tower plume as water vapour, with most of the balance, 45.8% being disposed of by reinjection. The flow of vapour from the cooling tower is not directly measured, and was calculated by mass balance across the station.

Minor losses via steam traps and the discharge of non condensable gases at the station total less than 1% of the total flow. Discharges of condensate from steam traps were estimated by calculating the expected heat lost through the pipe insulation.

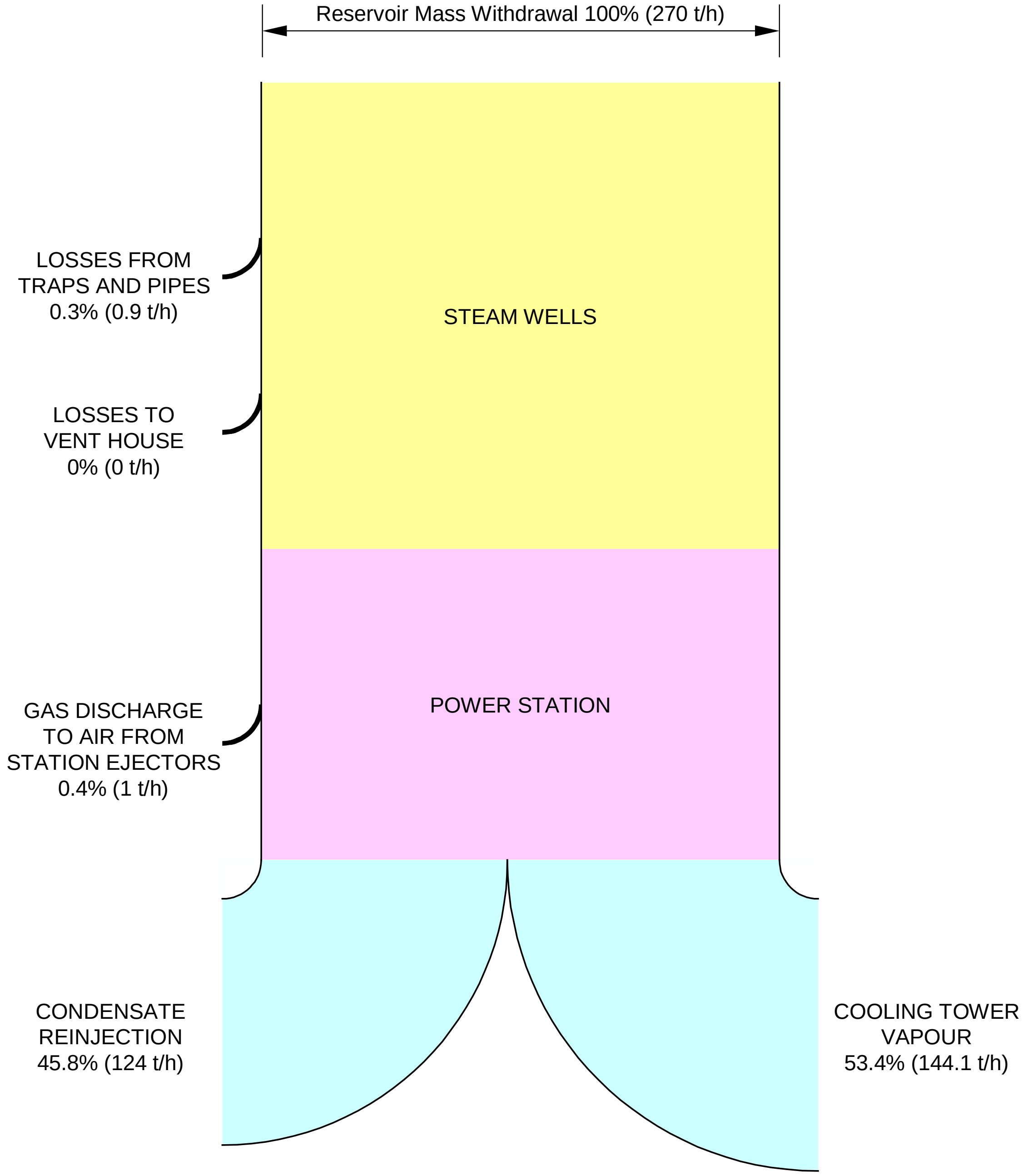


FIGURE 4.1 - POIHIPI MASS FLOWS

4.2 DISCUSSION OF ENERGY

System energy flows are shown in Figure 4.2. All energy has been reported relative to 20 ^{0}C, using the same basis as the Wairakei Energy Audit. Total reservoir thermal energy withdrawal is approximately 200 MW for a net electrical output of 32.7 MW.

A visual comparison between Figures 4.1 and 4.2 shows the similarities and differences in flows.

The Poihipi Road power station utilises evaporative cooling of the station cooling water by means of a mechanical draft cooling tower. In this case, the heat rejected by the generating plant is dissipated into the atmosphere by the flow of air and vapour from the cooling tower. The closed circuit cooling water system cycles large volumes of water from the turbine condenser (at about 34^{0}C) to the cooling tower, and back to the condenser at about 21^{0}C. Performing an accurate heat balance of the cooling water circuit based solely on measured flows and water temperatures was not accurate, since even relatively minor differences in water temperature, when applied to a very large flow, have significant impact on the calculated energy flow. Therefore, energy flows through the cooling system were calculated by energy balance across the station.

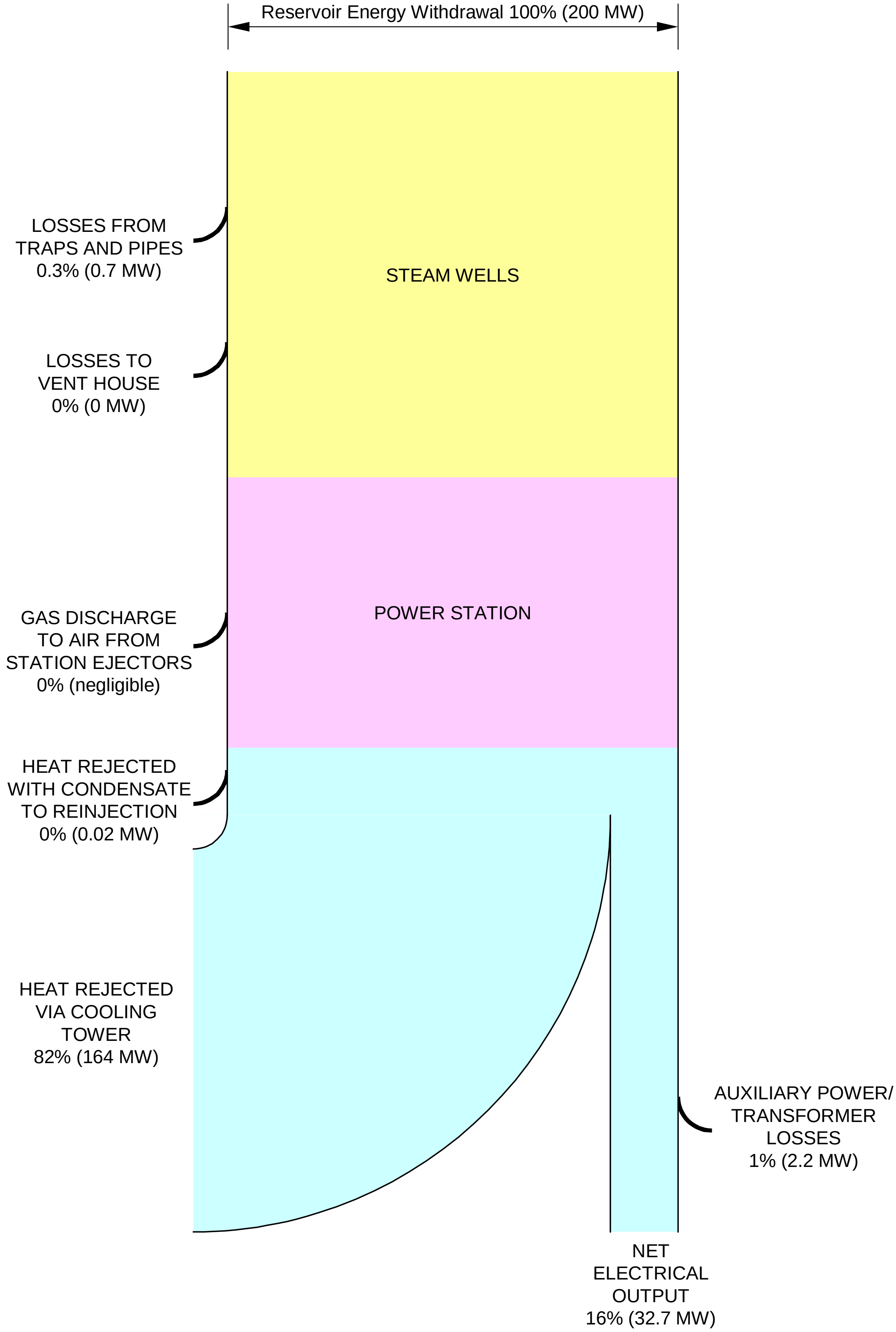


FIGURE 4.2 - POIHIPI ENERGY FLOWS

4.3 DISCUSSION OF EXERGY

Mass and energy are commonly understood terms. Exergy is an engineering term not in common usage. It refers to the maximum possible energy that is available to be converted to mechanical work between a source temperature and the surrounding sink temperature into which the fluid is discharged. It takes account of the Second Law of Thermodynamics, in that not all heat from a source can be converted into useful work (as in a turbine), and is calculated using the fluid property entropy. Entropy accounts for the loss of ability of a fluid to do work even if no energy is lost.

The overall rate of energy extraction from the field is calculated to be 57.1 MW relative to a 20^0C baseline temperature. This produces 32.7 MW net of electricity for export. The second law utilisation efficiency for the Poihipi facility under the June 2001 operating conditions is 57%.

The shape of the Sankey Exergy diagram (Figure 4.3) is similar to that of the Energy diagram (Figure 4.2), although less weight is placed on the low grade heat discharged from the cooling tower to atmosphere.

Given that there is minimal exergy loss between the wells and station, the second law utilisation efficiency for the station by itself is essentially the same as that calculated for the whole steamfield and station facility.

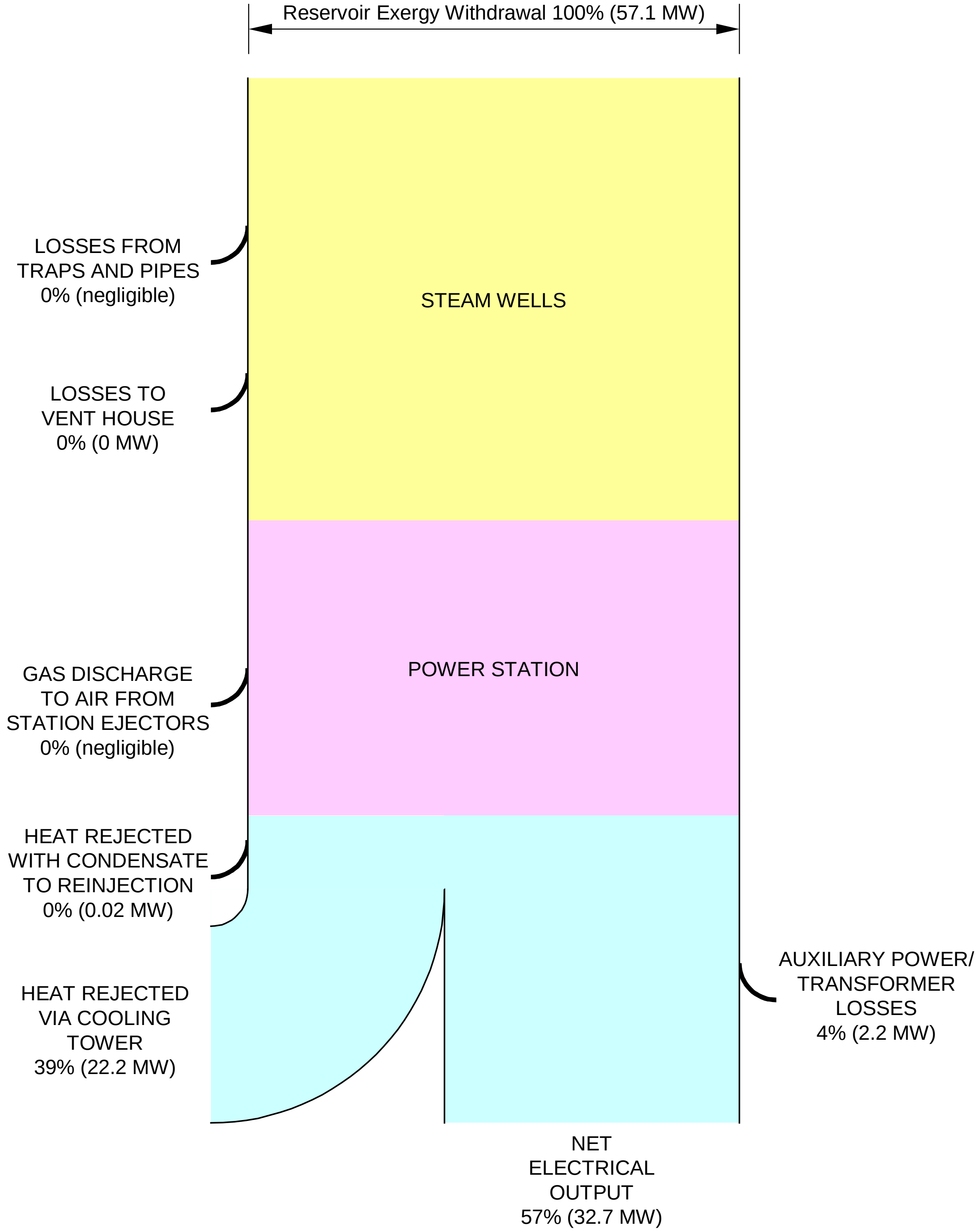


FIGURE 4.3 - POIHIPI EXERGY FLOWS

5. UTILISATION EFFICIENCY

5.1 PRESENT UTILISATION EFFICIENCY

In the past, utilisation efficiency has been defined in various ways. There are now international efforts to standardise these calculations for power generation (ASTM: E 974 – 83, DiPippo and Marcille 1984). Exergy is the appropriate way to evaluate the Poihipi facility in terms of what could ideally be produced from the geothermal fluid and what is actually produced by the facility. In this exergy study for Poihipi, it has been possible to relate the net power output to the ideal work available at the wellhead as a measure of the (second law) utilisation efficiency.

Figure 4.3 shows a net power output of 32.7 MW while total exergy at wellhead is 57.1 MW. Consequently at the time of the visit, the plant was operating with an overall second law utilisation efficiency of 57%.

Good published data is difficult to source and so it is not easy to make a comparison of Poihipi with other plants analysed at wellhead conditions. Some comparisons are available for the Geysers Geothermal field, USA (dry steam field) and at the Krafla Geothermal Field, Iceland (a liquid dominated geothermal field with double flash as at Wairakei) (DiPippo and Marcille). Each analysis has a different reference temperature that is the appropriate local sink temperature. The data values are plotted in Figure 5.1.

In order to compare the performance of various facilities with modern geothermal power plant, a utilisation efficiency curve has been derived for a recent steamfield and power plant design. This is plotted as the line in Figure 5.1. Efficiency has been plotted against steamfield production enthalpy as there is a strong relationship between the two. Families of curves could be derived for other plant designs, but their shape will be similar.

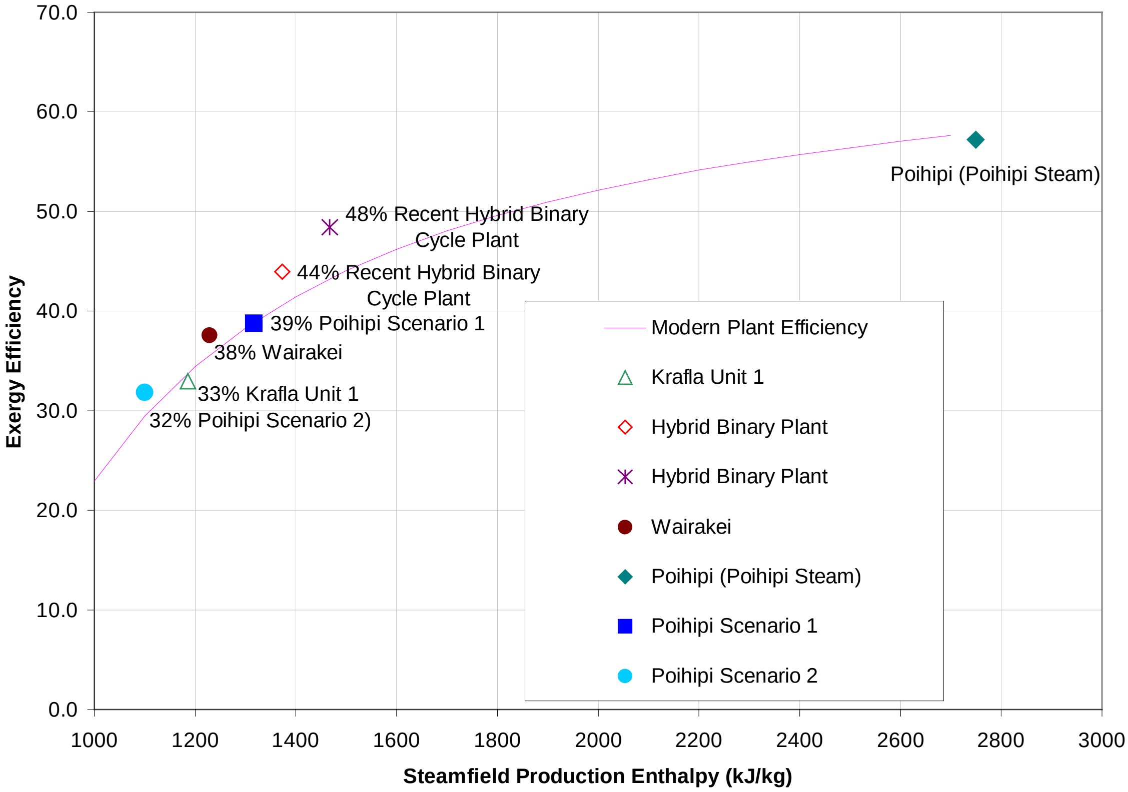
Poihipi is operating at an efficiency that is commensurate with modern plants operating on fields with production enthalpies of around 2750kJ/kg. With the present part-load operating scenario, Poihipi is somewhat penalised by relatively higher parasitic loads, such as running the cooling water circulating system for example.

Figure 5.1 also shows the performance of Wairakei based on an Energy audit conducted in 2000. Two recent hybrid binary cycle plants of confidential identity have also been included.

For reference, the cooling systems for the power stations identified on Figure 5.1 are as follows:

- Poihipi — Mechanical Draft Wet Cooling Tower
- Krafla — Mechanical Draft Wet Cooling Tower
- Wairakei — River Cooling
- Hybrid Binary Cycle Plant — Dry Cooling Tower

Figure 5.1: Poihipi Road Power Station
Comparison of Second Law Utilisation Efficiency



5.2 POIHIPI FULL-LOAD OPERATION

The installed capacity of the Poihipi power plant is under utilised in its present operating regime. Two scenarios were developed to investigate the effects of fully loading the Poihipi plant with steam piped from the Wairakei steamfield to the North.

5.2.1 Scenario #1: Additional Steam from Wairakei

Assuming sufficient steam is provided to Poihipi to fully load the turbine with a 44/56 split between steam from the Poihipi steam wells and steam sourced from 1150 kJ/kg fluid from Wairakei, a second law utilisation efficiency of 39% is calculated. This is noticeably reduced from the present Poihipi performance and the reasons for the difference are:

- Steam sourced form the main Wairakei field must be separated from the two-phase steam/water mixture. About 20% of the two-phase fluid mass flow is delivered as steam, with the balance being reinjected. There is heat carried in the reinjection flow, and its inclusion in the calculation reduces the overall utilisation efficiency.

- In order to discharge the separated water it was assumed to be pumped to a suitable reinjection well. The electrical power demand of the reinjection pumps also reduces the net electrical output of the station.

5.2.2 Scenario #2: All Steam from Wairakei

If the Poihipi plant is fully loaded with separated steam drawn from the Wairakei steamfield, a second utilisation efficiency of 32% is calculated. The reasons for the reduced utilisation efficiency are as above, but now with all steam sourced from the Wairakei two-phase fluid there is more separate geothermal water, resulting in additional heat carried via the reinjection flow and parasitic pumping load both increase, which reduces the overall efficiency.

6. CONCLUSIONS

- The major elements of the Poihipi steamfield and station were analysed to determine the flows of mass, energy and exergy in order to derive a utilisation efficiency for the Poihipi facility during a typical operating period on 16 June 2001 .
- Data adequate for that purpose was sourced from the Poihipi data acquisition system to enable the necessary calculations to be made.
- While there are some uncertainties in the measurements, sufficient alternative data or means of calculation were available to mitigate such shortcomings.
- Tabulated Summary of Results for Operation on 16 June 2001

	Mass (t/h)	Energy, rel to 20^0C (MW)	Exergy, rel to 20^0C (MW)
Withdrawn from Reservoir	270	200	57.1
Reinjected into Reservoir	124	0.02	0.02
Cooling Tower Discharge to Air	144	164	22.2
Gas and Trap discharges	2	0.7	0

- The power production from the plant was 32.7 MWe net during PB Power's visit in June 2001.
- Utilisation efficiency has been able to be determined. The appropriate efficiency (based on exergy), which assesses the performance of the plant against the theoretically available work, has been calculated to be 57%. This level of performance is typical of a well designed modern plant supplied with steam from dry steam wells.
- Two scenarios were developed to investigate fully loading the Poihipi station with steam sourced from the Wairakei steamfield. Based on a 44/56 split of steam from Poihipi and Wairakei the utilisation efficiency was calculated as 39%, reducing to 32% if all steam were sourced from Wairakei. The reduction in utilisation efficiency reflects the inherent loss of energy via the separation of water from the two phase fluid, and the increased parasitic load of the reinjection pumps.

7. REFERENCES

ASTM: E 974 – 83

- (1983 – Reapproved 1991) Standard Guide for Specifying Thermal Performance of Geothermal Power Systems. ASTM Designation: E 974 – 83

DiPippo and Marcille, 1984

DiPippo, R. and Marcille, D. P. (August 1984) Energy Analysis of Geothermal Power Plants. Geothermal Resources Council, TRANSACTIONS, Vol. 6, August 1984.

PB Power, 2000

PB Power, June 2000. Wairakei Energy and Efficiency Audit