WAIRAKEI ENERGY AND EFFICIENCY AUDIT

CONFIDENTIAL

Prepared for

CONTACT ENERGY LTD

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EXECUTIVE SUMMARY

The first turbine generator installed at Wairakei Geothermal Power Station was commissioned in November 1958. Most of the generating plant has now been operating for about 40 years. This report has been commissioned to look at the mass, energy and exergy flows within the steamfield and station assessing the overall utilisation efficiency of the Wairakei facility.

The report is a snapshot of the plant's operation on 15 February 2000, while operating in it's typical baseload mode. Performance will vary from this under different conditions such as part load operation, different air and river temperatures, different levels in Lake Aratiatia where pump capacity is influenced by the lake level, condenser leakage, etc.

Heat and exergy have been assessed relative to ambient conditions. For the 15 February this was 20 ^{o}C. Winter heat load will be different from summer heat load. The winter performance is expected to be better than summer performance, in terms of utilisation efficiency.

The steamfield and station are represented diagrammatically in Figure 2.1, while further station turbine arrangement information is shown in Figure 2.2.

All data for this report has been obtained directly by Contact Energy. PB Power's view is that the measurements have been undertaken diligently and that a reasonable effort has been made in ensuring that the data is to a suitable standard for operational management of the field and power station. This data was adequate for the purpose of this report to enable the necessary calculations to be made.

There are some uncertainties in the measurements. Where possible, uncertainties in measurements and data mismatches have been eliminated through selection of appropriate data. In cases where it has not been possible to resolve the differences the mismatches have been recorded.

Mass, energy and exergy flows are shown in Figures 4.1, 4.2 and 4.3 respectively.

Tabulated Summary of Results

	Mass (t/h)	Energy (rel. to 20^{o}C) (MW)	Exergy (rel. to 20^{o}C) (MW)
Withdrawn from Reservoir	5331	1694	436
Reinjected into Reservoir	1868	245	38
Discharged via Drains	1949	84	5
Discharged from Station	1460	916	128
Discharged to Air	188	206	48

The power production from the plant was 164 MWe net.

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 37%. The performance achieved is assisted from the benefit of the once through river water cooling system. The performance of the plant is excellent for the Wairakei field production enthalpy of 1227 kJ/kg and is directly comparable with the efficiency of a geothermal power plant of recent modern design.

1. INTRODUCTION

The first turbine generator installed at Wairakei Geothermal Power Station was commissioned in November 1958. Most of the generating plant has now been operating for about 40 years. This report has been commissioned to look at the mass, energy and exergy flows within the steamfield and station assessing the overall utilisation efficiency of the Wairakei facility.

A previous study has shown that engineering and operational changes have improved the utilisation efficiency with time (Thain and White, 1993).

This report audits the steamfield and the power station. The station is treated as a single entity rather than at the individual turbine generator level. The report focuses on the flows of mass, exergy and energy through the plant.

A PB Power engineer visited the Wairakei facility between 15 and 17 February 2000 to obtain data and to discuss details with site staff. The results of this data collection and the subsequent analysis are summarised in this report.

The report is a snapshot of the plant's operation on 15 February 2000, while operating in its typical baseload mode. Performance will vary from this under different conditions such as part load operation, different air and river temperatures, different levels in Lake Aratiatia where pump capacity is influenced by the lake level, condenser leakage, etc.

Heat and exergy have been assessed relative to ambient conditions. For the 15 February this was 20 ^{o}C. Winter heat load will be different from 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 Steamfield is located about 8km NE of Taupo. It is spread over an area of about 15km^2.

The Wairakei facility was the first commercial development of a liquid dominated (wet) geothermal field for electricity generation in the world. Engineering work has been undertaken over the years in order to maintain generation and to improve the efficiency of the facility.

Since the 1980's the steamfield has been operated as a two pressure system. The naming convention to distinguish between the two pressures in the steamfield is to identify the higher pressure system as Intermediate Pressure (IP) and the lower pressure system as Intermediate Low Pressure (ILP). In the steamfield, the IP and ILP steam line pressures are about 5bg (IP) and 1.6 bg (ILP) respectively. At the station, steam manifold pressures are 3.8bg and 1.2bg respectively.

All steam wells are connected to the IP steam system. Wells that discharge a mixture of steam and water, discharge through separators or flash plants. The majority of IP wells have the separated geothermal water from the IP separation stage reused and passed through to an ILP flash plant to produce additional ILP steam.

After separation of the steam, the separated geothermal water is either reinjected or discharged via a drainage system to the Wairakei Stream and then to the Waikato River. Water discharged to the drainage system passes through silencers where some steam is discharged to the atmosphere. The water for reinjection is collected from some of the flash plants and piped down to the river flats near the power station for injection.

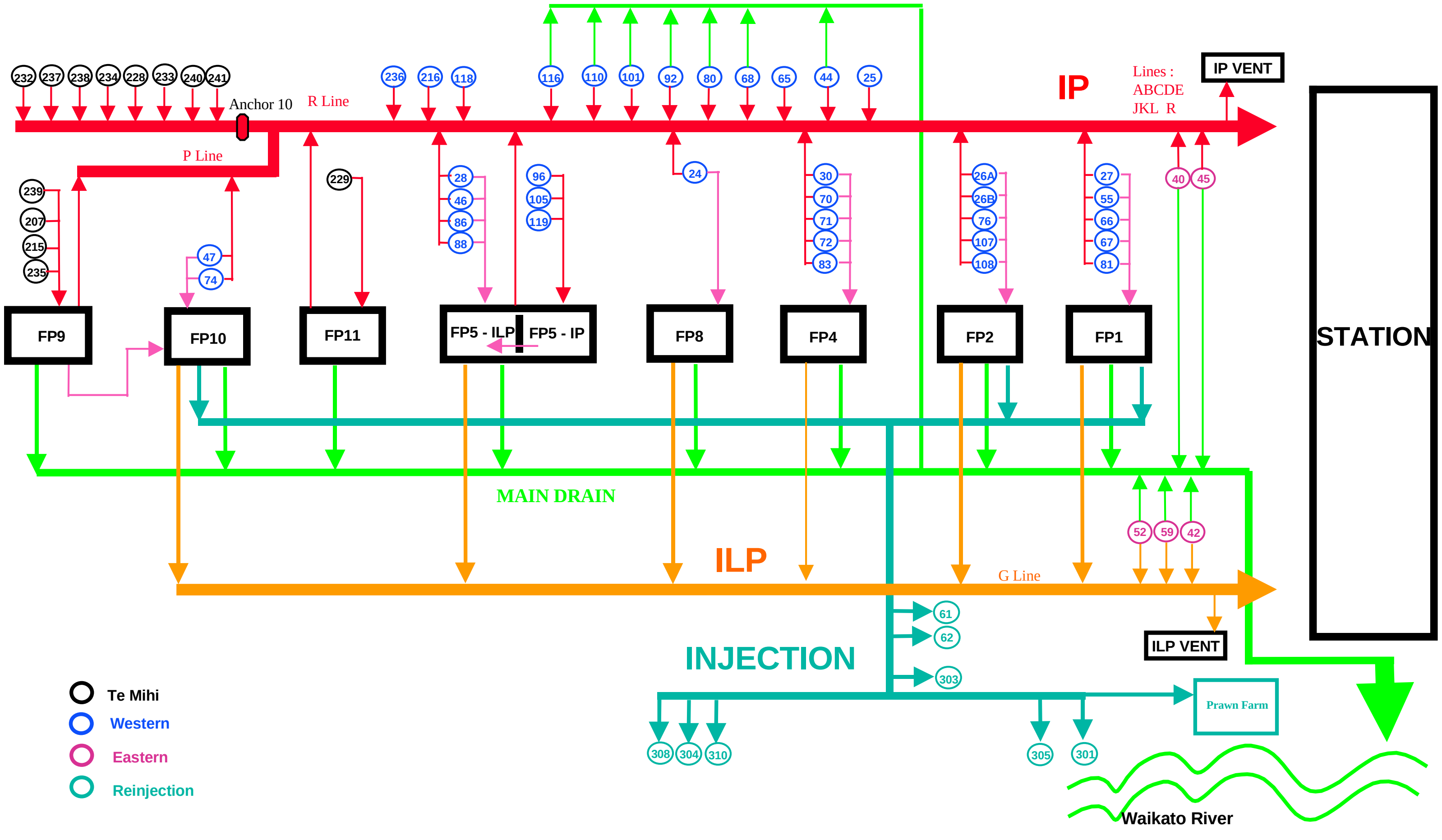
The steamfield and station are represented diagrammatically in Figure 2.1. The figure includes:

Production Wells: The wells and their respective connections are shown on the diagram.

Flashplants: The individual flashplants are shown on the schematics. The individual wellhead separators are not specifically identified.

Injection Wells: The injection wells used for injecting separated geothermal water are shown on the schematic.

FIGURE 2.1 WAIRAKEI STEAMFIELD - SINGLE LINE SCHEMATIC - AS AT 15/2/2000



2.2 STATION

The Wairakei Power Station is located adjacent to the Waikato River. The Station consists of A and B Stations with their associated support facilities. Turbines were commissioned between 1958 and 1964. An ILP turbine was commissioned in 1996. A simplified steamflow and turbine arrangement is shown in Figure 2.2. The Station receives steam from the steamfield at both the IP and ILP pressures.

A pump house draws water from the Waikato River for condenser and other cooling requirements within the plant. The station operates a once-through cooling system. In this analysis the flow of the cooling water is not used, but the temperature is used as the ambient (sink) temperature in the production of the Sankey diagrams for energy and exergy that are included in section 4. This study has assumed that all the heat dissipated around the station is captured by cooling water. A small amount of heat will be lost to the atmosphere but this is negligible compared with the river heat load.

The Power Station has a number of auxiliary systems. In terms of this audit, only the gas extraction system has any measurable flow not discharged with the condensate. All other auxiliary systems have been grouped together to appear as parasitic electrical load requirements.

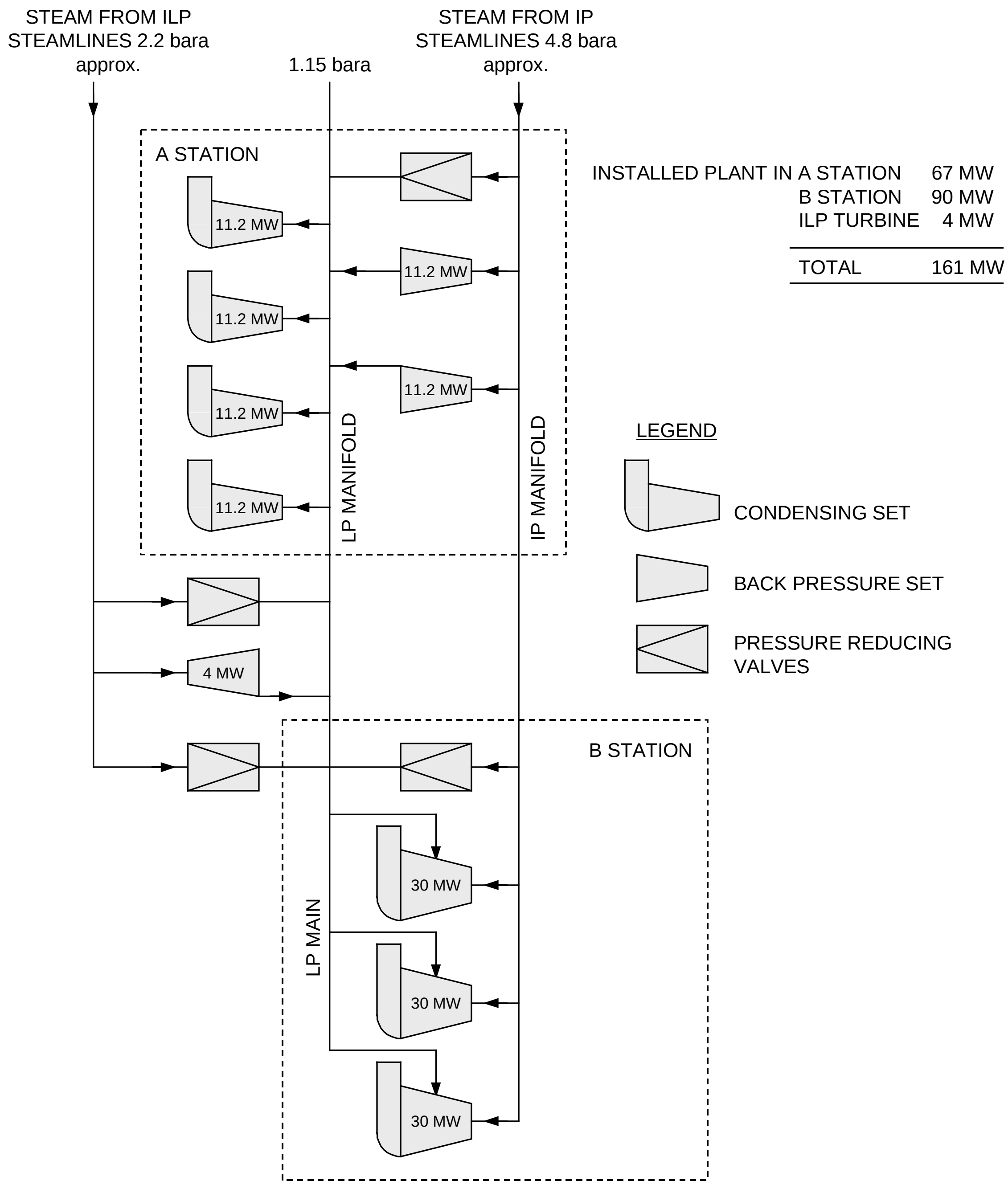


FIGURE 2.2 SIMPLIFIED STATION STEAMFLOW AND TURBINE ARRANGEMENT

3. SOURCE AND QUALITY OF DATA

All data for this report has been obtained directly by Contact Energy. PB Power's view is that the measurements have been undertaken diligently and that a reasonable effort has been made in ensuring that the data is to a suitable standard for operational management of the field and power station.

Measurements are recorded manually and by 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%. Data that is logged by computer based systems is supplemented by manual records. These manual measurements are of variable accuracy depending on the conditions under which the measurements are made. In reviewing the manual records, particularly when the steam flow rates are corrected for operating conditions (compared with standard reference pressures of 2 and 4 bara), they gave logical results.

In the steamfield some wells cannot be individually measured because of the way they are connected into the steam field production system. Estimates have been derived in these circumstances. The mass and enthalpy estimates are based on the most recent output tests on individual wells. These tests are made at close to operating wellhead pressures using the lip pressure and weir method. Contact Energy's practice is to take the individual wellhead pressures, equate this to a mass flow and enthalpy based on the output test, and then compare it to the overall output of the flashplant concerned. This method usually obtains a reasonable match between calculated and measured flashplant output. Accordingly this practice was repeated for this audit.

Most of the steam flow is produced from dry steam wells and from flashplants, which are monitored by the computer data acquisition system.

Automated data is logged at least hourly. The steamfield manual measurements are obtained on a less frequent basis, but essentially once per week with data accumulated over a 1 to 3 day period. This frequency for manual measurements had been fortnightly at the time of the audit (an almost complete set of data was able to be obtained on 15 February). The timing of the manual measurements adds some difficulty in interpreting data because the measurements are made over a period of time rather than being available at a particular time. Offsetting this timing issue, the station and steamfield are run in baseload mode. A review of generation since 1 January 2000 showed that there have only been 6 days when the station output has been outside a 4MW band in terms of output, with station gross output typically being between 167 and 171MW. Consequently there will rarely be significant change in measurements and timing of measurements is therefore a secondary consideration.

Accuracy of the steamfield flow data is affected in several ways.

Firstly, a large portion of the steamfield flow is from dry steam wells discharging into R-Main. Some of the individual wells are not metered separately and the individual well flow has to estimated. It is therefore not possible to perform cross-checks between the individual wells and steam flow measurements made in the steam pipelines.

Secondly, monitoring attention is mainly on steam flow. Pressure gauge readings are generally of secondary importance in terms of system operation and the pressure gauges are checked for accuracy less frequently. To derive energy and exergy in this report, the pressure measurements were used to determine thermodynamic property data.

Thirdly, estimates have to be made in some places. Reliance is placed on recent output tests. Cross checks are made between mass flows expected to be entering a flashplant and mass flow leaving a flashplant, and generally a good match is obtained.

In seeking to obtain a mass balance it is not always possible to determine whether any mismatch is due to estimate error at the inlet or measurement error at the outlet. For this report, any mismatch has been stated.

4. SYSTEM MASS, ENERGY AND EXERGY FLOWS

Data was collected on 15 February 2000 when the plant was operating at 164 MW nett capacity.

The data was analysed and the calculated results are shown in Figures 4.1, 4.2 and 4.3 that follow. The width of the flow streams in the figures are approximately to scale. The calculated numbers are shown in each flow stream.

4.1 DISCUSSION OF MASS

Approximately 5300t/h of geothermal fluid is being withdrawn from the field.

The largest proportion of this mass (85%) is coming from the two-phase IP wells that discharge a mixture of steam and water.

Figure 4.1 then shows much of this flow entering separators and flash plants, with a large percentage leaving as water either to surface or to reinjection.

There is a 269t/h mismatch (equivalent to 6% of the incoming flow) between all flow estimated to be entering separators and flash plants, and flow measured as leaving these vessels. This is regarded as a good match, given the multitude of measurement points and the inherent uncertainties.

In terms of individual flash plants, the greatest mismatch is at flash plants 4 (16% difference) and 9/10 (9% difference).

Water vapour discharged to the atmosphere from silencers was calculated using the measured air pressure in the field coupled with the measured weir flows. Although vapour can be seen rising from the drains, it has been assumed that this evaporation is negligible and that the majority of water that enters the drain system will flow to the river.

Approximately equal quantities of separated geothermal water were discharged to the River and to reinjection.

At the time of measurement, the Prawn Farm was not receiving any water. However, a review of records showed a demand of up to 80t/h.

Approximately equal quantities of IP steam are produced from the steam wells and from the two-phase wells.

Most of the ILP steam is sourced from second stage flashing of geothermal water at the flash plants.

Losses of condensate from steam traps were determined by calculating the heat lost between the wells and station. The associated heat loss was calculated back to an equivalent condensate loss at an average pipe pressure. A further adjustment was needed for the ILP line to ensure that entropy did not increase.

The steam line condensate produced equates to about 2% of the steam entering the steam mains. Note that the diagram simplifies condensate mass flows as a single line from the IP steam stream, although calculations were done separately for the IP and ILP lines.

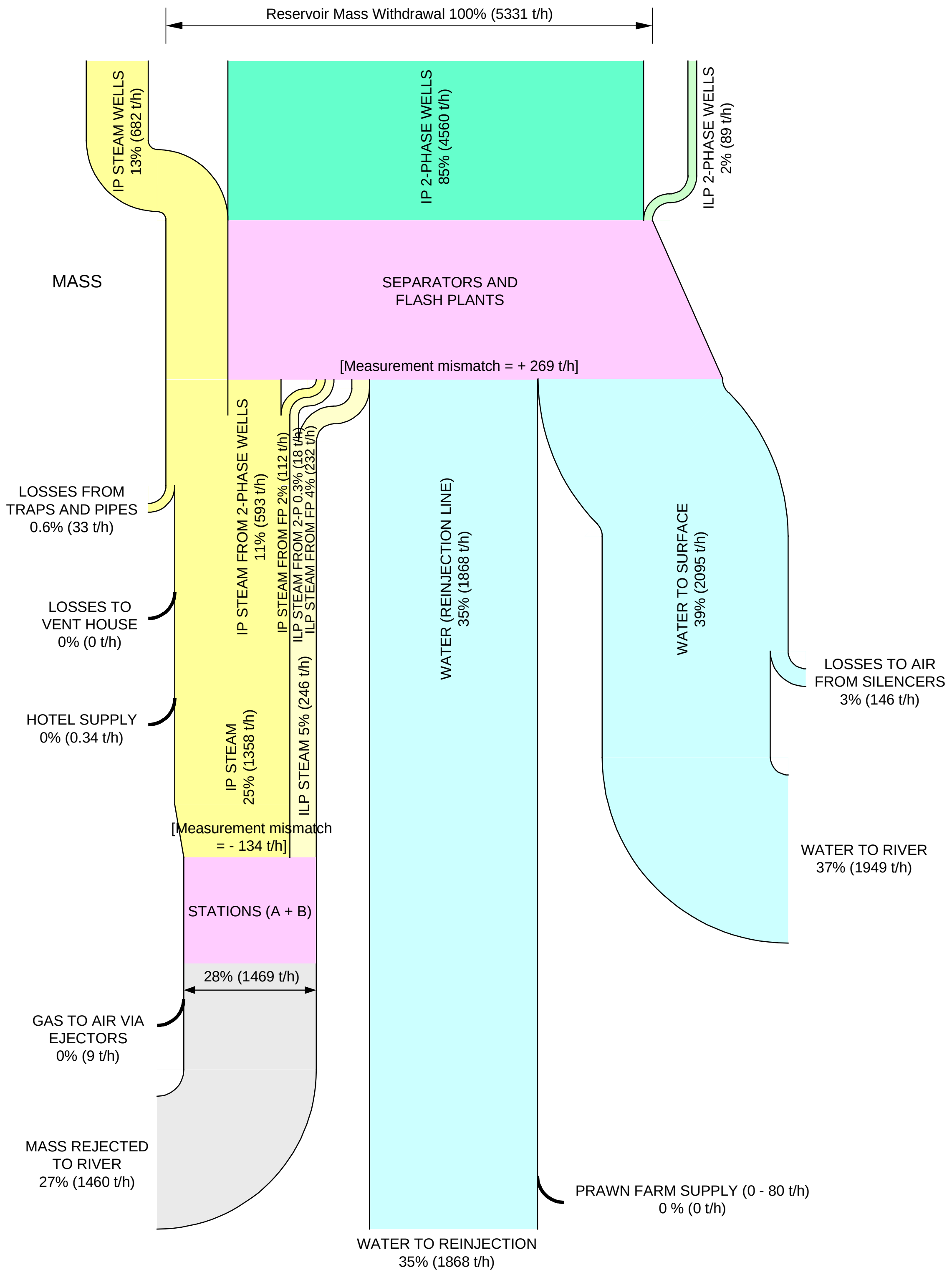


FIGURE 4.1 WAIRAKEI MASS FLOWS

There is a mismatch of 134 t/h between the steam entering the station and the steam measured as coming from the steamfield. That is, the steamflow measured from the steamfield is 134 t/h higher than the steamflow measured at the station. This equates to an 8% difference. We have not been able to resolve this difference.

The diagram treats the Station as a black box. Other than the discharge of a small amount of gas from the gas stacks above the station, all steam entering the station is condensed by the cooling water flow.

The cooling water flow into the station is not shown.

4.2 DISCUSSION OF ENERGY

System energy flows are shown in Figure 4.2. The river temperature at the time of measurement was about 20 ^oC. All energy has been reported relative to 20 ^oC. Total reservoir thermal energy withdrawal is approximately 1700 MW for a net electrical output of 164 MW.

A visual comparison between Figures 4.1 and 4.2 shows the similarities and differences in flows. The width of the steam flows compared to the water flows, exhibits the higher energy content of the steam.

About 30% of all heat energy withdrawn from the reservoir is via the IP steam wells.

It has been assumed that energy loss between the wellhead and separator is negligible.

Minor energy mismatches are evident at the separators and flashplants. The mismatch of 51MW out of 1185 MW arriving at the separators is regarded as excellent agreement.

Losses to air from silencers were calculated using weir flows and measured air pressure.

Heat loss from drains was calculated. It has been assumed that mass loss by evaporation was negligible.

Some heat is lost to the air from the reinjection line. This was calculated using theoretical pipe heat loss curves and pipe geometry as the measured temperature drop was within the limits of instrument accuracy.

The Prawn Farm was not receiving heat at the time of measurement.

The measurement mismatch at the station is 125 MW out of 1210 MW. This is a calculated value based on mass and pressure measurement, and so, is a direct consequence of the mismatch in the mass flow data. As for mass flow, this difference has not been able to be resolved.

In assessing the total heat to the river, all energy not in the form of electricity, or the gas discharged to the atmosphere, is assumed to discharge to the river. The flow of cooling water and condensate discharged from the station is not measured, so a crosscheck is not possible. If the mismatch discussed above is due to metering errors at the station steam mains, then the heat that is discharged to the River from the Station was between 916 MW and 1041 MW (relative to 20 ^oC).

The total rate of heat addition to the river from Station condensate and geothermal water is 1000-1125 MW (relative to 20 ^oC).

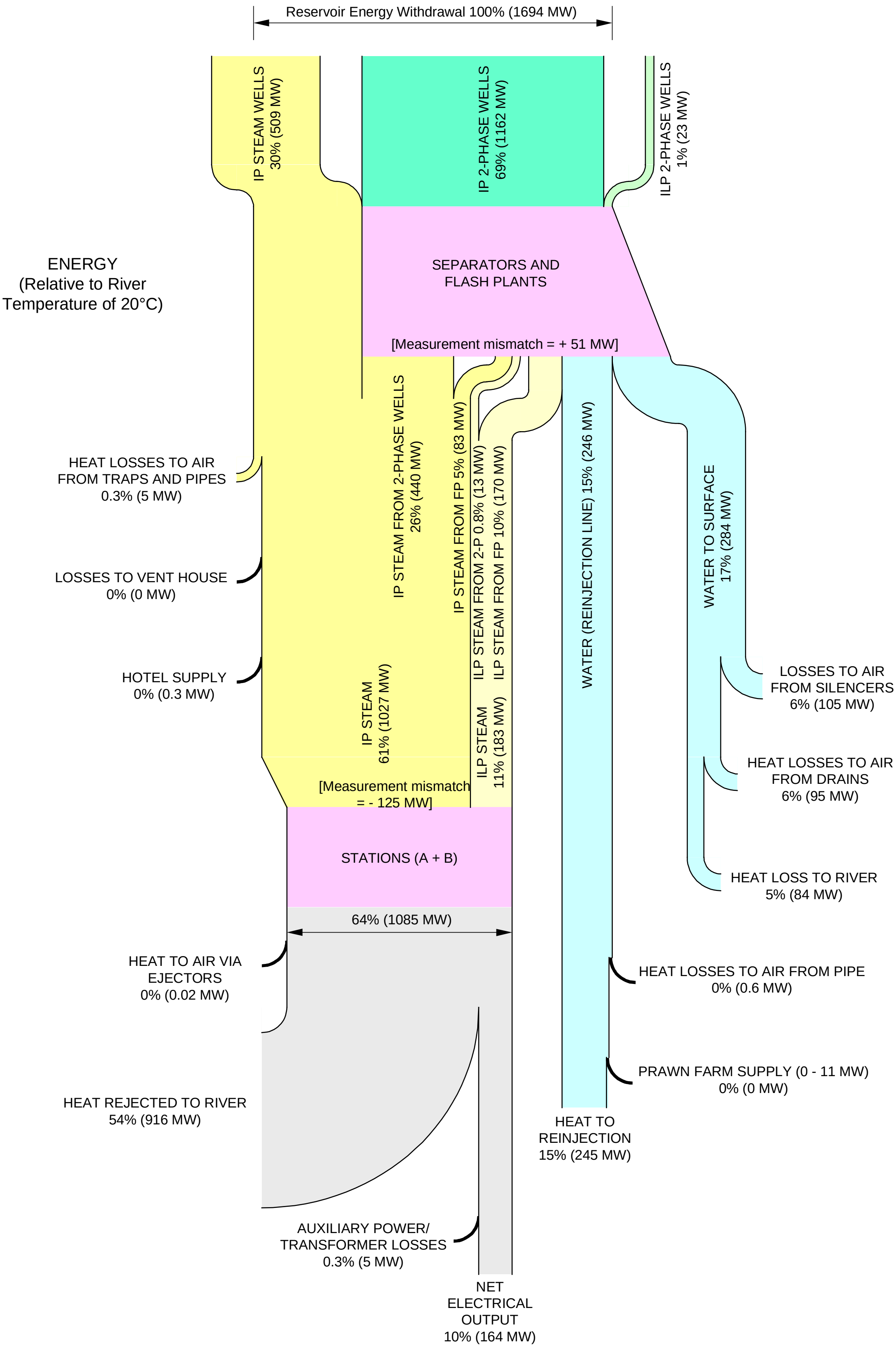


FIGURE 4.2 WAIRAKEI ENERGY FLOWS

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 energy that is ideally available between a source temperature and the surrounding sink temperature into which the fluid is discharged. It takes account of a property called entropy, which in turn is related to the Second Law of Thermodynamics. Entropy is a property that accounts for the fact that not all heat from a source can be converted into useful work (as in a turbine).

The overall rate of exergy extraction from the field is calculated to be 436 MW. This produces 164 MW of electricity for export. The second law utilisation efficiency for the Wairakei facility is 37.6%.

The shape of the Sankey Exergy diagram (Figure 4.3) is similar to that of the Energy diagram (Figure 4.2), although greater weight is placed on the value of the IP Steam and lesser weight is placed on the value of the water.

There is a 16 MW mismatch (equivalent to 6% of the incoming flow) at the separators. This is a reasonable match given estimating and measurement uncertainties. It is a calculated value based in part on the measured mismatch in mass.

Less than 20% of exergy is lost with water streams. Only 5 MW is discharged to the river out of a total of 83 MW in the water leaving the separators.

An exergy mismatch of 54 MW exists at the Station inlet. This is 15% of the exergy flow arriving at the Station. This mismatch is a calculated value and is a direct consequence of the mismatch in mass flow, so resolution is not possible.

Of the flow of 297 MW of exergy at the Station, 164 MW is converted into useful work for export. This is an efficiency of 55%. The plant is very efficient under the operating conditions experienced.

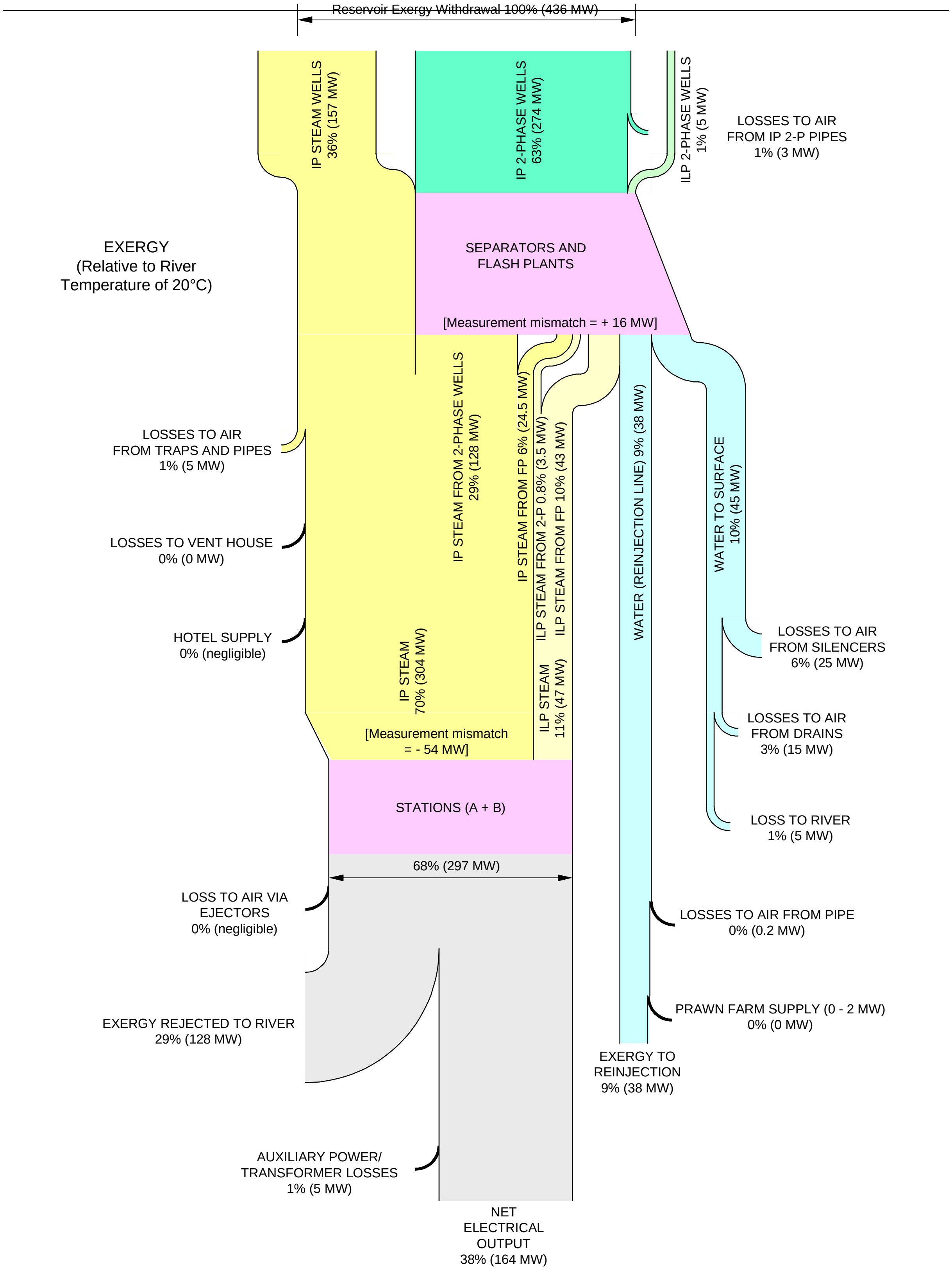


FIGURE 4.3 WAIRAKEI EXERGY FLOWS

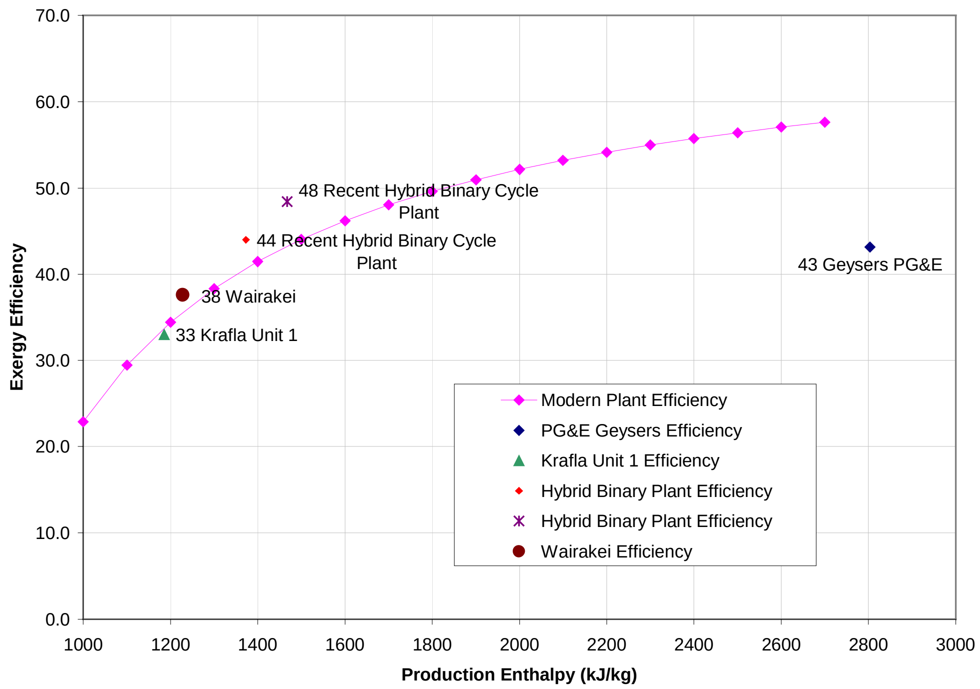
5. UTILISATION EFFICIENCY

5.1 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 Wairakei facility in terms of what could ideally be produced from the geothermal fluid and what is produced by the facility. In this exergy study for Wairakei, 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 164 MW while total exergy at wellhead is 436 MW. Consequently at the time of the visit, the plant was operating with an overall second law utilisation efficiency of 37.6%.

Figure 5.1: Comparison of Second Law Utilisation Efficiency



Good published data is difficult to source and so it is not easy to make a comparison of Wairakei 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 the Wairakei facility with a geothermal power plant that would be installed today, a utilisation efficiency curve has been derived for a recent steamfield and power plant design. This is plotted in Figure 5.1. Efficiency has been plotted against wellhead 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.

Figure 5.1 also shows the performance of two recent hybrid binary cycle plants of confidential identity.

It can be seen that Wairakei is not as efficient as more modern plants operating on fields that have higher production field enthalpies.

From Figure 5.1 it is observed that Wairakei is an efficient plant operating at a production enthalpy of 1227 kJ/kg.

Wairakei operates with high efficiency at the Wairakei production enthalpy. Wairakei's performance is similar to what would be achieved in recent modern designed plant. This good performance is enhanced by the ability to operate the condensers at a low vacuum, which is a direct benefit of the once through river water cooling system.

6. CONCLUSIONS

- The major elements of the Wairakei steamfield and station were analysed to determine the flows of mass, energy and exergy in order to derive a utilisation efficiency for the Wairakei facility.

- Data adequate for that purpose was sourced from the Wairakei facility to enable the necessary calculations to be made.

- There are some uncertainties in the measurements. Where possible, uncertainties in measurements and data mismatches have been eliminated through selection of appropriate data. In cases where it has not been possible to resolve the differences the mismatches have been recorded.

- Tabulated Summary of Results

	Mass (t/h)	Energy (rel. to 20^{o}C) (MW)	Exergy (rel. to 20^{o}C) (MW)
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- The power production from the plant was 164 MWe net during PB Power's visit in February 2000.

- 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 37%. The performance achieved is assisted from the benefit of the once through river water cooling system. The performance of Wairakei's plant is excellent for the field production enthalpy of 1227 kJ/kg and is directly comparable with the efficiency of a geothermal power plant of recent modern design.

7. REFERENCES

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