WAIRAKEI POWER DEVELOPMENT EFFICIENCY STUDIES

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SUMMARY - The ongoing development of the Wairakei Geothermal Power Station has been a process of continual refinement of resource utilisation. This paper reviews past and recent studies into the improvement of energy recovery for generation purposes, and in particular the potential for low enthalpy energy recovery. These studies show that between 19 and 26 MW of additional net generation could be produced from the existing resource. Further direct use of the cooled fluid for aquaculture, and the prospects of mineral recovery are also examined.

1.0 INTRODUCTION

The development of Wairakei Geothermal Power Station has been characterised by a continuing search for improved efficiency in utilisation of the geothermal resource and generating plant. Earlier initiatives were primarily aimed at maximising plant load factor and total energy output. More recently the changing environment as reflected in ECNZ policy, resource management constraints and financial investment options has given impetus to further improvements in efficiency of Wairakei's resource utilisation.

Like all energy efficiency programmes the current investigations at Wairakei began with an energy audit which identified a number of thermal losses, and proposed solutions for recovery of a significant amount of waste energy. This paper concentrates on some of the studies undertaken into the more efficient use of the low enthalpy separated water flow. Two areas of investigation are examined:

- Additional electrical generation.
- Direct use applications of low grade heat such as aquaculture.

The potential for mineral recovery is also discussed, as the final stage of fluid utilisation prior to reinjection.

For the purposes of this paper a quantitative assessment of utilisation trends can be made if utilisation efficiency is defined as:

$$\eta = \frac{\text{net power generated} + \text{rate of heat use for process purposes}}{\text{rate of heat extraction from reservoir (above 15°C)}}$$

This definition does not make allowance for the effects of reinjection or take into account the utilisation associated with mineral extraction.

2.0 HISTORICAL IMPROVEMENTS IN RESOURCE UTILISATION

The following is a brief overview of the projects implemented over the years at Wairakei Power Station in order to extract the utmost output from the geothermal fluid. Decisions to proceed with projects were based on thorough technical and financial analysis.

2.1 Pilot Hot Water Plant

The power development at Wairakei was initially conceived around a two pressure steam supply to the station, at 12.5 barg (HP steam) and 3.5 barg (IP steam). It was also decided to build a pilot hot water scheme to establish the feasibility of taking separated HP and IP water from the steamfield to a flashplant located between 'A' and 'B' stations, from which additional IP and LP (0.05 barg) steam would be generated. Due to the limited state of knowledge concerning two phase transmission systems, the pilot hot water scheme involved a pumped water supply from the steamfield separators, an elevated header tank, and mixing of HP and IP water (attemperation) to maintain the line pressure at least 0.6 bar above the fluid vapour pressure and so prevent boiling within the transmission system. The pilot hot water scheme was commissioned in the latter half of 1963 which coincided with the commissioning of the final 30 MW turbines in 'B' station. Unfortunately the commissioning of the pilot hot water scheme also coincided with an increase in fluid enthalpy during the early stages of field exploitation. Consequently, the water output of the 7 wells connected to the scheme dropped markedly and the plant saw less than 12 months service.

2.2 Triple Flash System

Following the demise of the pilot hot water scheme, investigations into double and triple flashplants located within the steamfield showed the concept to be feasible. In 1970 the recommendation was made to install centralised two stage flash plants to take HP water and produce IP and LP steam for transmission. This overall concept was referred to as "triple flash", with the first stage flash occurring at individual well heads to produce HP steam, and the remaining two flash stages occurring at the flashplants to produce IP and LP steam. A new transmission line (G Line) was commissioned in 1974 to carry the low pressure steam to the station.

The completion of the "triple flash" system made a significant contribution to station generation, and improved the efficiency of resource utilisation as shown in Table 1 and Figures 1 and 2.

2.3 Derating

The Wairakei steamfield was never able to produce sufficient HP steam to fully load the HP machines. Commencing in 1963, the station HP manifold pressure was progressively lowered from its design value of 12.5 barg to 6.5 barg by 1980. This helped maintain mass flow from the HP wells by reducing backpressure at the wellhead. By 1980 it was apparent that derating to a two pressure system (IP and LP) would potentially increase total station generation due to the increased output of the HP wells when derated to IP conditions. (Thain and Stacey, 1984).

Derating was completed in November 1982, with decommissioning of the four HP machines and subsequent modifications to wellhead separators and flashplants. An increase in gross generation from 136.6 to 140.1 MW was recorded.

2.4 Te Mihi

1983 saw the extension of the steam transmission system to make use of production from three existing wells in the Te Mihi area.

With steamfield run down averaging 5% per annum it was not long before additional steam winning was required and in 1985, the first new production wells to be drilled at Wairakei since 1968 were drilled in the Te Mihi area of the field. A total of eight new wells were drilled over the period 1985 to 1989, with three intercepting the *dry* steam cap which had developed over this part of the field, and two others having good production characteristics from a deeper liquid resource. These five wells have been connected and are supplying a significant percentage of the station's steam supply.

As a result of tapping a steam resource, these Te Mihi wells have little separated water associated with discharge and consequently have increased the overall resource utilisation efficiency.

2.5 R Main

Following on from the Te Mihi extension an additional IP steam main ("R Main") was installed, commencing operation in late 1992 to reduce the overall pressure losses in the steam transmission system. This, in turn reduced the well head pressure on all the IP production wells, resulting in an increase in fluid flow from each well and an increase in flashed IP steam.

With all of these initiatives in place, Wairakei's nine remaining turbines now operate fully loaded with a gross output of 157 MWe.

'ABLE 1 : SUMMARY OF WAIRAKEI UTILISATION DATA

YEAR	MASS WITHDRAWN (M tonnes)	ENTHALPY (kJ/kg)	NET ENERGY (GWHe)	UTILISATION (%)
1952	1.93	1095	0	0.00
1953	5.12	1035	0	0.00
1954	7.33	1051	0	0.00
1955	10.68	1075	0	0.00
1956	21.02	1106	0	0.00
1957	20.3	1122	0	0.00
1958	21.5	1078	6	0.10
1959	37.49	1071	169	1.61
1960	50.32	1122	384	2.59
1961	42.2	1122	491	3.95
1962	51.72	1105	761	5.08
1963	74.22	1142	1004	4.51
1964	72.41	1140	1194	5.51
1965	64.61	1150	1255	6.43
1966	62.36	1143	1268	6.78
1967	59.68	1126	1058	6.00
1968	48.01	1148	1207	8.34
1969	55.68	1132	1243	7.52
1970	53.79	1126	1185	7.46
1971	54.56	1105	1174	7.43
1972	51.88	1110	1175	7.79
1973	48.47	1116	1162	8.20
1974	47.13	1113	1249	9.09
1975	46.29	1110	1272	9.45
1976	47.03	1091	1233	9.18
1977	45.05	1117	1158	8.78
1978	48.89	1083	1189	8.58
1979	45.85	1069	1056	8.24
1980	47.68	1067	1152	8.66
1981	46.98	1055	1076	8.31
1982	47.11	1042	1136	8.87
1983	40.78	1118	1144	9.57
1984	44.37	1135	1203	9.10
1985	38.43	1147	1106	9.56
1986	42.91	1128	1171	9.22
1987	45.95	1096	1200	9.10
1988	47.82	1091	1181	8.65
1989	45.36	1168	1180	8.47
1990	43.74	1165	1217	9.09
1991			1173	
1992			1257	

Notes: Net energy is based on year ended 31 March of the following year while mass withdrawn and enthalpy are for calendar years. Thus a systematic error is built into the calculation of utilisation efficiency.

FIGURE 1 : WAIRAKEI UTILISATION EFFICIENCY

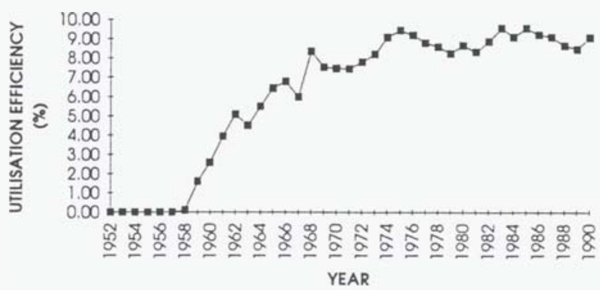
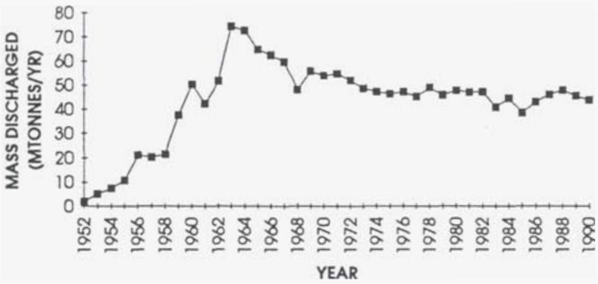


FIGURE 2: WAIRAKEI UTILISATION



3.0 ON-GOING IMPROVEMENTS

3.1 Resource Management Act

New Zealand is one of the first countries in the world to legislate for the sustainable management of its physical and natural resources. This legislation was enacted by the passing of the Resource Management Act in October 1991. This legislation stipulates that all users of natural resources must manage these resources in a sustainable, efficient, and environmentally acceptable manner. Geothermal resources are recognised within the legislation as a renewable and sustainable resource. This has further stimulated ECNZ's efforts to improve its utilisation of its geothermal resources. The following sections of this paper identify the work and research studies which ECNZ are undertaking to make more efficient use of the Wairakei geothermal resource. Whilst these studies focus on a Wairakei application, they are also applicable at Ohaaki and any future geothermal development.

3.2 Energy Audit

In early 1993 an energy audit at the Wairakei Power Plant was undertaken, which tracked the process by which steam was converted to electricity. While the turbines themselves were found to have a comparable efficiency to modem machines, a total of 14.5 MW of losses was attributed to station piping and pressure reducing valves at the time of the survey.

Within the existing station confines it was realised that there was only limited scope for reducing the 6.7 MW of pipe losses identified. However, the 7.8 MW loss attributed to the pressure reduction process from "G line" to the station LP manifolds was an area of loss that could be rectified.

3.3 Pressure Reducing Valve Energy Recovery

The low pressure steam brought fiom the steamfield flashplants via "G Line" is delivered to the station at about 1.9 bara, and then transferred to the A and B station LP manifolds (approximately 1.1 bara) via pressure reducing valves. This throttling process is thermodynamically inefficient and by replacing the existing pressure reducing valves with two rotary expander turbines, studies show an additional 3.5 to 4 MWe could be generated from steam presently being delivered to the station.

3.4 Low Enthalpy Energy Recovery

At Wairakei, the conventional flashed steam power cycle results in under-utilisation of the heat energy contained in the discharged separated water. Consideration has been given to using this hot water in the past for power generation but costs have been prohibitive.

However the commitment to reinjection of the separated water from the Wairakei field has improved the economic viability of further energy and mineral extraction from this source. This is because the Reinjection Project will gather approximately 90% of separated water currently being discharged from the steamfield, into a single line to transmit fluid to reinjection wells located on the river flats adjacent to the Wairakei Power Station. Hence, fluid gathering costs will not have to be borne by the low enthalpy energy recovery power plant.

Collection of the separated water for reinjection is planned to occur in two stages:

Stage 1: 2,400 t/h
Stage 2: 3,500 t/h

With this hot fluid transmitted to one point beside the existing station prior to reinjection, the possibility of plant which recovers the unused energy becomes more attractive financially.

Two systems are currently being investigated as a means of generating power from the separated water. These are:

- Organic Rankine Cycle
- Atmospheric and Sub-atmospheric Flashed Steam Cycle

Both studies are based on the use of 3,500 t/h of separated water at a temperature of 127°C and the use of river water for system cooling.

a) Organic Rankine Cycle

The studies show that the Organic Rankine Cycle (ORC) operating with an end point temperature of 87°C would generate an additional 15MW net from the above fluid.

The advantages of the ORC plant are:

- Well proven technology.
- Small Modular Unit construction, which better lends itself to the staged implementation of the reinjection project.
- Simple civil engineering site requirements.
- Short construction period.

Heat exchanger fouling by silica scaling may lead to a degradation in output. However, tests are planned to determine the scaling potential of the separated fluid during its flow cycle time within the heat exchanger system.

b) Atmospheric/ Sub-atmospheric Flash Steam Cycle

Atmospheric flashed steam turbines have been in service at Wairakei for the past 35 years. However no large scale use of sub-atmospheric steam has yet been attempted. Mitsubishi have developed and marketed a small 0.5 MW sub-atmospheric steam turbine and studies reported in Hibara et al, 1990 indicate the optimum technical design sub-atmospheric flash pressure to be **0.4** bar abs.

As the flash pressure is lowered more steam and hence generation is available, however the costs increase markedly due to the large increase in steam specific volume and hence in physical size of steam plant.

Initial enquiries of turbine manufacturers concerning sub-atmospheric turbine plant of the size envisaged, indicated construction of such plant was practical, and that significant reductions in turbine size and cost could be gained by accepting some variation from optimum inlet pressure and reduction in turbine efficiency.

In order to select an optimum sub-atmospheric flash pressure an assessment was made of net revenue versus second stage flash pressure. (Net revenue being the value to ECNZ of additional generation less capital and O&M cost of the plant). This showed, for the Wairakei situation, the best sub-atmospheric pressure to be close to 0.5 bar abs. The studies have shown that a Double LP Flash Steam Cycle plant operating with an end point cycle temperature of 81°C would generate an additional **20** MW net from the available fluid.

The installed cost per kW appears to be very similar for both the Organic Rankine Cycle and Flash Steam Cycle options.

3.5 Mineral Recovery

Much work has been carried out at Wairakei and elsewhere into the deposition characteristics of the silica contained in separated geothermal fluid. Recent Wairakei work has concentrated on inhibiting silica deposition following the lowering of the separated water below its silica saturation temperature limit. This work was principally aimed at enabling more useful energy to be extracted from the fluid before it is reinjected. The work has shown chemical inhibition to be practicable but the process will add a significant cost to the operation of the low enthalpy energy recovery systems.

At Kawerau the Tasman Pulp and Paper Company have developed a commercial prototype pilot plant to extract several grades of silica for use as fillers to improve newsprint quality. The pilot plant is currently operating and has a proven production output of 500 kg/day of precipitated silica which when accumulated, is sufficient for full scale paper machine trials. (Harper and Thain, 1991).

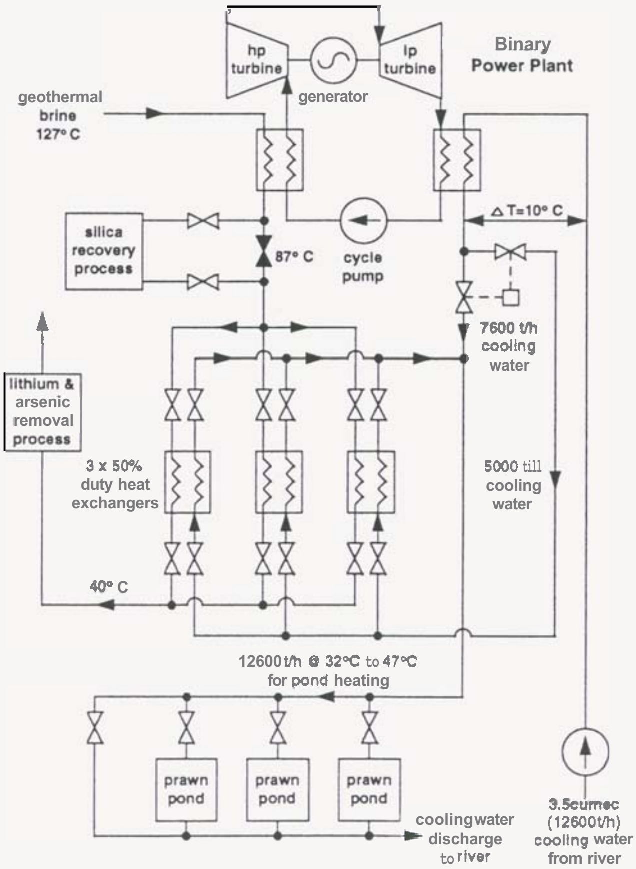
Geothermal fluid which has had a major portion of its silica content removed is expected to pose much less of a problem to reinject than a fluid supersaturated with silica. It also makes recovery or removal of the other mineral elements contained in separated water a much less difficult **task.** Thus clean up **of** geothermal fluid to **a** level which would make the fluid acceptable for discharge to natural water ways is **now** a distinct possibility.

The commercialisation of silica extraction from geothermal **separated** water is now technically achievable, however full development requires a committed market customer.

3.6 Direct Heat Use

At Wairakei opportunity exists for further utilisation of the separated geothermal water following the fluid's exit from the low energy recovery plant and possible silica extraction plant. On exiting from these plants the fluid is still at a useful 80 to 70°C. At this temperature the fluid can be used to heat clean Waikato River water for servicing the needs of a growing local aquaculture industry.

FIGURE 3 : BINARY PLANT AND BRINE HEAT EXCHANGER COOLING WATER SYSTEM



Aquatech Developments presently operate a 2½ hectare prawn farm operation utilising the hot geothermal separated water presently being discharged to the Waikato River. They are currently planning to expand their operation to initially a *6%* hectare and then eventually to a 30 hectare development. The average thermal heat requirements for each hectare of prawn farm pond is about **6.5** *MW* th. Thus a 30 hectare development would require around 200 *MW* th on an annual basis. Figure **3** shows **a** diagrammatic outline of the heat extraction process contemplated **for** Wairakei.

4.0 SUMMARY OF OVERALL TRENDS IN UTILISATION

From the preceding descriptive sections, it will be evident that the overall trend has been one of improving utilisation of the Wairakei geothermal resource. Further improvement can be expected as greater use is made of the current separated water flow.

A comparison of figures 1 and 2 indicates the early years at Wairakei were associated with high absolute utilisation (in terms of **mass** discharged) and low utilisation efficiency. **A part** of this poor performance was due to a policy of discharging production wells whether they were needed or not, as part of a reservoir proving exercise. Such wasteful operational practices are no longer employed.

A second contributing factor to the initial lower utilisation efficiency was the amount of separated water associated with the high pressure (HP) steam supply. **As** the HP manifold pressure was reduced the HP separator and wellhead pressures reduced. **As** the separator pressure reduced the proportion of steam flashed off the HP well discharge was increased, thus increasing efficiency.

A step increase in efficiency can be seen after 1973/74 as the flash plants were commissioned. These flash plants enabled extra steam and electricity generation from what was otherwise unused water.

A further step increase in efficiency in 1982/83 can be linked to derating and Te Mihi production.

The deterioration in efficiency between step increases is associated with an ongoing trend of decreasing enthalpy associated with cool recharge of the reservoir.

Not shown on these graphs are the benefits from R Main's installation in 1992 which has effectively derated the IP wells. This has lead to near record generation levels for very little mass discharge increase implying a significant efficiency improvement.

The plans outlined in this paper will not result in any increase in the mass withdrawal from the Wairakei field, but will further improve the utilisation efficiency of the resource. The electric power generation enhancements will increase the installed plant capacity of the station by approximately 22 MWe to 179 MWe. This will increase the power stations overall utilisation efficiency from around 9% to around 10.2% ie an improvement of about 10%.

The planned 30 hectare aquaculture development will require a direct heat load of around 200 *MW* th, which equates to a stand alone utilisation efficiency **of** 11.8%.

Thus the developments outlined, when implemented, will increase the overall resource utilisation efficiency to around **22.0%.** This **is** more than double the present utilisation efficiency of around 9%.

5.0 CONCLUSIONS

- New Zealand has substantial geothermal resources to call upon to meet its future energy needs. The excellent operating record achieved by Wairakei, over the past **35** years, has shown conclusively that geothermal power is a commercially proven, safe and reliable energy source.

  Under proactive management, a fields utilisation efficiency can be improved significantly over time with Wairakei being a prime example.

  The Resource Management Act is helping to give further impetus to improve utilisation efficiency and the Wairakei developments identified in this paper will pave the way for efficient and effective use to be made of geothermal resources in the future.

  The extraction of silica from separated geothermal water, or the inhibition of silica deposition, is of strategic importance to the full utilisation of geothermal resources, as it makes low temperature reinjection feasible and thus paves the way for expanded energy extraction.

6.0 ACKNOWLEDGEMENTS

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7.0 REFERENCES

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