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DIRECT USE APPLICATIONS OF GEOTHERMAL ENERGY IN NEW ZEALAND

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ABSTRACT

Direct use of geothermal energy in New Zealand is relatively small (approx. 7000 TJ/yr) because of cheap electricity, but is increasing. At present, the greatest use is as industrial process heat in a timber mill at Kawerau where fluid from a high-temperature geothermal re-servoir is used directly to heat combustion air and shatter sprays in chemical recovery boilers, heat black liquor, and to pre-heat boiler water. Clean steam, obtained using a heat exchanger, is used to dry paper, heat boiler water, and generate electricity for the mill. Other significant uses are in space heating, timber drying, fish farming and orchid growing.

INTRODUCTION

New Zealand lies astride the junction of the Pacific and Australian lithospheric plates. Active volcanism associated with subduction of the Pacific plate beneath the North Island re-sults in abundant high-temperature geothermal resources in a triangular shaped area called the Taupo Volcanic Zone (Fig. 1). In some other parts of the North Island low enthalpy springs occur associated with deep circu-lation of meteoric waters; these springs generally emerge at active tectonic faults. In the South Island a narrow zone of low enthalpy springs occur; these are also as-sociated with major tectonic faults (Fig. 1).

Because of the abundance of high-en-thalpy geothermal resources, and the wide-spread availability of cheap hydro-generated electricity (US3c/kWhr, wholesale) and natural gas, little effort has been made to explore and develop low-enthalpy geothermal resources except for bathing. In addition, most of New Zealand has a moderate winter climate in which temperatures at night rarely fall below –5 °C and during the day are about 10-15 °C. Most other direct uses are associated with the wastewater from geothermal power stations.

Table 1. Direct heat use in New Zealand, at end of 1999; taken from Thain and Dunstall (2000).

Use	Location	Installed Capacity (MWt)	Annual Use (TJ/yr)
Process heat	Kawerau	210	5500
Agricultural drying	Kawerau, Reporoa	29.3	>253
Space heating	Rotorua, Taupo	722	700
Fish farming	Wairakei	18.6	363
Heating greenhouses	Kawerau, Taupo		
	Total:	>307.9	>7081

This paper has been compiled and con-densed from Anderson (1998), Dunstall & Foster (1998), Lund & Klein (1998), McLachlan (1998), Scott & Lund (1998).

INDUSTRIAL PROCESS HEATING

A large timber pulp and paper mill is situated on the Kawerau Geothermal Field, and geothermal steam is used directly for heating combustion air and shatter sprays in chemical recovery boilers, heating black liquor, and to pre-heat boiler water. Clean steam, obtained using a heat exchanger is used to dry paper, heat boiler water, and generate electri-city for the mill. Engineering details of the equipment are given by Hotson (1994). The use of geothermal steam and other fuels in the mill are controlled to optimise costs using a sophisticated computerised system (Hotson & Everett, 2000).

DOMESTIC AND COMMERCIAL HEATING & BATHING (Anderson, 1998)

Beneath Rotorua City are several shallow aquifers containing near-boiling water associ-ated with outflows from a deeper, high-tempe-rature geothermal system. These outflows ori-ginate from an upflow region that manifests itself at the surface in the Whakarewarewa Thermal Area where there are many natural thermal features (Allis & Lumb, 1992).

The earliest uses of the geothermal re-sources in Rotorua, and which pre-date Euro-pean settlement (1830 A.D.), were for bathing, washing and cooking in these thermal features by the native Maori people. Today, geothermal is applied to a variety of domestic and com-mercial heating to provide “mineral” water for bathing. Increased usage since 1950 has cau-sed a decline in natural activity at Whakare-warewa. To counteract this, the government implemented in the 1980s a control program that included closure of all geothermal wells within 1.5 km of the centre of Whakarewarewa and payment for use of geothermal fluid (O’Shaughnessy, 2000). These measures ap-pear to have been successful in stopping the decline and many thermal features have been rejuvenated (Scott & Cody, 2000).

Domestic Group Heating Schemes

There is a housing development with a geothermal group heating scheme. There are 13 units on this site, which share a well with six other dwellings on adjoining properties. Six-teen of the total are supplied with a circulating supply of hot water from a single heat ex-changer; the other three use geothermal fluid and have their own, smaller heat exchanger. This is a relatively early example of a scheme that distributes secondary water rather than re-circulating geothermal fluid. The heat is used for space heating, domestic hot water heating, and heating small swimming pools. This system has been successful but there have been a number of design weaknesses which have contributed to piping corrosion, internal and external, and difficulty in getting adequate circulation to some users.

Institutions

At the Queen Elizabeth Hospital in Rotorua, geothermal fluid is used for space heating, and for domestic hot water heating. In addition, some of the partially cooled geothermal water is collected, cooled further and de-gassed in a concrete vat, then piped to the Hydrotherapy Department for use in the treat-ment of skin ailments and arthritis.

Hotels

Many hotels and motels in Rotorua and Taupo use hot geothermal water for space heating and for spa pools. For example, the Millennium Hotel in Rotorua uses geothermal water for space heating, domestic hot water heating, pool heating (a medium-sized swimming pool and a number of spa pools), all using fresh water.

Swimming Pools

This is one of the major uses of geothermal in Rotorua and Taupo, both public and private. Pools contain either town water which is heated by geothermal, or geothermal water ("mineral" pools).

The Aquatic Centre in Rotorua is a relatively large scale public swimming pool facility. This complex has two indoor swimming pools (Fig. 2) and a larger outdoor pool; all three are geothermally heated. In addition, geothermal energy is used for space heating and for domestic hot water heating. All of the geothermal fluid is passed through a single plate-type heat exchanger, which heats the secondary water, which is a circulating system of town water. Because of the high capacity of the geothermal heating system, the supply for showers and hand basins is heated on an as-required basis, avoiding the cost of installing a large storage calorifier. The cold mains water feed is passed through a small heat exchanger fitted with an automatic temperature control. There is a small buffer tank in the circuit, sized to absorb the variations in temperature in the hot water that occur when there is a big change in the demand.

To minimise chlorine odour, a once-through ventilation system with a relatively high air flow rate has been installed. No air is re-circulated. The incoming air is heated to main-tain the building's internal temperature. A heat pipe, heat recovery unit has been incorporated to significantly reduce the high heat losses that would otherwise occur. The hot, moist, chlorine-laden air being extracted is passed through a heat recovery unit, which uses it to preheat the incoming air. This unit recovers about 75% of the heat in the exhaust air. The heating of the fresh air is completed by a heating coil through which low-temperature hot water is circulated.

The Aquatic Centre has annual maintenance costs for its geothermal system of about US$10,000. If natural gas were used to pro-vide the energy, the gas cost would be around $75,000.

Balneology

The Polynesian Spa in Rotorua is one of the best known examples of direct mineral pools (Fig. 3). Some of the pools are built around natural springs with the inflow coming up through the sandy bottom of the pools, while other pools use piped-in mineral water.

The reputed therapeutic benefits for geothermal waters have long been exploited. Originally it was intended that Rotorua would become a spa in the European fashion. The Bathhouse, opened in 1908 complete with the latest balneological equipment and related treatments then in vogue in Europe, was built for this purpose. The Bathhouse is now closed but hydrotherapy still continues at Queen Elizabeth Hospital.

Cooking

Cooking has been a use of geothermal heat from pre-European times. Some house-holds in Rotorua still have small, enclosed steam boxes, outdoors, which are used for steaming food. A hot pool at Whakarewarewa is also used to cook food (potatoes, sweet corn) for sale to tourists.

GEOTHERMAL GREENHOUSES

(Dunstall & Foster, 1998)

Waste geothermal steam available from the Kawerau geothermal field is used to heat greenhouses in which capsicums (bell peppers) are grown for both local and export markets. The total greenhouse area is 5250 m^2, consisting of 3600 m^2 in an early timber frame, fan-ventilated, single plastic-covered design built in 1982, and an area of 1650 m^2 in a modern, fan-ventilated, twin skin steel and aluminium framed greenhouse built in 1994. Heating requirements are relatively large compa-red to other greenhouses in New Zealand, due to the high minimum night and day temperatures needed for the crop and the cool Kawerau climate at night.

The capsicum crop grows in specially graded pumice, and is fertilised and wa-tered using hydroponics. The climate is computer controlled, with humidity regula-tion and a CO_2 enrichment system. The ir-rigation system is controlled by solar sen-sors, dispensing nutrients at a rate depen-dent on the uptake rate in the plants. Ma-ture plants grow to a height of approxi-mately 3.5 m, at which point they are dis-carded and the growing process is restar-ted from new seedlings. A high quality crop is grown, with a yield of 20-30 kg/m^2 annually.

Steam for the greenhouse is supplied from a 2-phase fluid line fed by several deep wells. The primary separator for this fluid is 500 m distant, so a small separator mounted beside the 2-phase line is used. Flows to the greenhouse are small, so steam can be tapped from this small separator and the remaining water retur-ned to the 2-phase line. The steam supply is at 270°C and a pressure of 1.5 MPa (15 bar) in the 2-phase line, and a pressure control valve reduces and maintains this at 0.5 MPa (5 bar) for the 50 mm greenhouse steam supply line, which is buried in a shallow trench. Motorised valves connec-ted to temperature controllers in the green-house then determine the flow of steam admitted to distribution headers, which in turn supply a network of 25 mm diameter heating pipes. Condensate and residual steam from the heating pipes flow to atmosphere. The black steel heating pipes are installed above the crop, supplying heat to the air and radiant energy to the plants. Wet and dry bulb sensors are used for humidity and temperature regulation as part of the control system.

The annual energy usage is about 700,000 kW/h, at a cost of about NZ$4900 (US$2200). The unit energy cost is therefore NZ$0.007/kWh, or about NZ$ 5.50 per tonne of steam. The steam flow is not metered; instead a flat rate is charged each year, based on historical condensate flow data. The capital cost for the heating system was NZ$44,000. Assuming a 20 year equipment life the discounted cost (12% discount rate) is NZ$0.036/kWh ($0.029 equipment + $0.007 energy). Heating a similar greenhouse with electricity would cost about 11c/kWh (7c energy + 4c installation). The use of geothermal energy therefore results in a saving of $38,000 per year, but part of this saving is offset by extra transportation costs.

Most heat is lost from greenhouses by air leakage and wind effects due to poor construction. Air leakage rates have a severe impact on economics especially when CO_2 enrichment and humidity control are used because these are much more expensive to provide and control than temperature. Modern plastic covered greenhouses may use as little as 30% of the heat needed for an older glass covered greenhouse. Typical heat loss rates at Kawerau are 3.5 W/m^2K in plastic greenhouses compared to 12 W/m^2K in glass covered greenhouses. The new twin-skin plastic greenhouse achieves these low heat losses without loss of solar light transmission required for plant growth.

Carbon dioxide is an effective growth stimulant for plants, and there is an opportunity to use the CO_2 present in the geothermal fluid at Kawerau, however, the plants would react adversely to the small amounts of hydrogen sulphide present in the non-condensible gas. Even very low H_2S concentrations of 0.03 mg/kg can have negative effects on the growth of plants (National Research Council, 1979). Purification of the available CO_2 would therefore be required before it could be used in the greenhouses. At Kawerau, bottled carbon dioxide is used at a rate of about 50 kg per day, to provide CO_2 levels of 800 mg/kg when the greenhouse is closed and 300 - 350 mg/kg while venting. The steam supplied to the greenhouses each year for heating purposes contains almost exactly the quantity of bottled CO_2 used each year. With appropriate treatment, the geothermal steam might ultimately be as valuable for its CO_2 contribution as for its heating value.

TIMBER DRYING (Scott & Lund, 1998)

The New Zealand forestry industry is based on plantation grown pine (*Pinus radiata*), which is harvested when the trees are 25-35 years old. Compared to many other timber species, it has very high moisture content (up to 130% by weight) and must be dried. The main reasons for drying are to set the sap and prevent warping. The sap usually sets at 57 - 60 °C, and warping is prevented by establishing a uniform moisture content through the thickness of the wood, which is best achieved in a kiln. The drying rate varies with the species of wood and with thickness. Natural air-drying is slow and expensive (because the land cannot be otherwise used); kiln drying is the quickest and simplest way to add value to the timber. A timber-drying kiln is a large oven in which the enclosed heated air is circulated to draw moisture from the timber and then exhaust it to the atmosphere. The heat energy is generally supplied by hot water at high pressure and temperature to heat exchangers in the kilns. Fans distribute the hot air at velocities of 5-8 m/s and at kiln temperatures of 80-140 °C.

A geothermal drying kiln is associated with the Tasman Pulp and Paper Plant at Kawerau. This kiln uses steam at inlet temperature of 180 °C, which produces a temperature of 150 °C in the kiln. Batches of 80-100 m^3 of sawn timber, each piece separated by about 2 cm using spacers, are moved into the kiln on three rail-mounted tracks (Fig. 4). Fans (2 m diam.) produce an air flow velocity of 9 m/s across pipe heat exchangers, and the circulation direction is reversed (by computer) every 1.5 hours. The moisture is reduced to 10% after about 20 hours, then the timber is put through a cool-down period for 2 hours, and finally reconditioned for 6-8 hours at 90-100°C which increases the moisture content to 20%

(Fig. 5). This creates uniform moisture content throughout each piece of timber. The typical timber dried is planks 5 x 10 cm in size, however, wider material requires a lower temperature of 120ºC and longer time. The dried product is stained by sap on the surface, which is removed in the finish planing operation. Prior to using geothermal energy, the timber was dried at 70ºC for four days - a much more costly operation. The entire procedure is monitored and controlled by computer. The final product sells in New Zealand for US$150-200 per m^3 thus adding 50 - 100% to the price. Kiln drying costs about US$20 per m^3 of which the geothermal energy is about 5-10% of this cost.

FISH FARMING (Lund & Klein, 1998)

Malaysian Freshwater Prawns (*macro-bra-chium rosenbergii*) are farmed in ponds within a 10.2 ha area, near Wairakei Geothermal Power Station. There are nine ponds varying from 0.2 to 0.35 ha in area and 1.0 to 1.2 m in depth (Fig. 7). The length to width ratio of the pond surface is approximately 20:1. The sides are sloped for stability and for ease of harvest. The bottom material is composed of an impermeable volcanic ash that also stores nutrients for the prawns. The ponds are kept at a temperature of 24 ($\pm$1) ºC. A temperature probe controls the flow of water into the ponds and an aerator is used to obtain vertical mixing of the pond water. Without this vertical mixing, the pond would become temperature stratified, reducing the production of prawns.

Water for the ponds comes from two sources: a plate heat exchanger (at 55 ºC) (Fig. 8) and river water (at 10ºC). Water is circulated throughout the system from a storage and settling pond that is kept at 21ºC. About 90% of the water is recirculated with the 10% makeup water coming from the river. Water is circulated through the plate heat exchanger at a rate of 250 t/hr in summer and 400 t/hr in winter. The primary side of the plate heat exchanger takes wastewater from the Wairakei geothermal power plant; about 4000 t/hr of 90ºC wastewater is discharged from the plant and flows across the pumps supplying the plate heat exchanger. The geothermal water cannot be used directly in the ponds due to the presence of sulphur, lithium and arsenic.

At present, the farm produces about 16 tonnes of prawns per year. The life of the prawn starts in salt water inside a building in breeding tanks, and ends in the freshwater ponds outside where they are harvested after 9 months averaging 30 to 40 per kg (about 30 g each). The breeding tanks hold 100-150 breeding stock; one male to five females. After about 18 months the males are replaced. The female prawns spawn five times each year in brackish water (1/3 saltwater and 2/3 freshwater), and produce between 20,000 to 80,000 larvae per spawning. A total of one million larvae are produced per cycle, giving total production of 9 million post-larvae per year. After spawning, the larvae are siphoned off into a catching bucket and placed in the larval tanks (Fig. 9). They are fed three times a day with a mixture of crushed mussels and scrambled eggs. They undergo 11 different moults to metamorphose into a post-larvae stage in 30 days. They are then moved to nursery ponds at 28 ºC (Fig. 10). Here they grow from 0.01 g to 4-6 g in four months, and are fed pellets containing fishbone and minerals three times a day. After four months in the nursery, the prawns are transferred to outdoor ponds for their final growth of a further five months. The prawns are moved manually using a net with mesh openings that catches only the largest ones. They are fed pellets, but zooplankton growing in the ponds provide additional food. Prawns are voracious eaters and will turn cannibalistic if undernourished. Two kilograms of food produces one kilogram of prawns. After five months, the ponds are drained, the prawns picked up manually from the bottom, and then transferred to an on-site hatchery for washing before they are taken fresh to a restaurant or snap frozen for future use (Fig. 11).

The stocking rate in the outdoor growout ponds is about 30 per square meter or 20-30,000 prawns per pond, depending upon the size. At harvest time, 400-500 kg are produced from the smaller ponds and 800-1000 kg produced from the larger ponds. Ninety percent of the harvested prawns are sold in the adjacent restaurant; the remainder are sold to gourmet restaurants. Over a recent three-year period, the restaurant has served more than 30 tonnes of prawns to more than 45,000 visitors. The restaurant offers a plate of 16 prawns for US$15. The farm is also a commercial tourist attraction with visitors able to have a half-hour tour of the hatchery, five times each day.

Prawn farming is labour-intensive with high overheads: six hectares cost US$330,000 per year to operate, but return about US$60,000 per ha. Factors which have contributed to the success of the farming are the availability of cheap hot water, cheap flat land, and tourism in the area.

GROWING ORCHIDS (McLachlan, 1998)

Tropical orchids (*Phalaenopsis*) are grown in greenhouses on Wairakei Geothermal Field. These grow wild in the jungles of southwest Asia, with a few species extending northwards to Taiwan and Sikkim, and southward to northern Australia. In nature, the plants are living on the surface of trees (epiphytes) and the stems hang downward, with the leaves arranged in a spiral fashion. However, under cultivated conditions the flower stems are tied vertically and grow upward (Fig. 12). They are shade-loving plants, requiring a light intensity of only 1000 foot candles (10,700 lx) or only 10% of full sunlight.

The orchids are grown for cut-flower production. The plants are grown in artificial monsoon conditions, similar to those experi-enced by the plants in their natural habitat. This enables production at any time of the year to meet market requirements in Japan and elsewhere. The company has approximately 250,000 plants in its greenhouses (Fig. 13), laboratory and quarantine area; of these, 30,000 are mature plants. Each plant produces on average two stems of blooms each year upon reaching maturity (two years old), and these blooms are specially packed to produce the best possible return from overseas markets. An individual plant-performance recording system enables the company to breed selectively. In addition to good breeding, parent plants must also have good colour, shape of bloom, and be prolific in their bloom production per stem, to qualify as breeding stock.

The greenhouses cover an area of 0.8 ha and are kept at temperatures of 26 ^{o}C during the day and 21 ^{o}C at night. The greenhouses are heated using a small amount of the steam from three wells which supply the nearby Poihipi power plant. These wells are 450-500 m deep and each can produce 120 t/hr at 0.7 MPa. Some of the steam supplied to the greenhouse is passed through a shell-and-tube heat exchanger (Fig. 14). The heating is computer-controlled and is supplied to the greenhouse by large hot water heaters (using fans and finned heat extractors) or by steam radiators and fans (Fig. 15). The energy supplied to the greenhouses is about 200 MJ/hr for (peak).

Fertiliser is applied daily through a series of computer-controlled electric solenoids so that each plant can take both water and fertiliser up through the capillary watering system used on the growing tables. This enables the plants to be fed and watered without water lying in the leaf joints, which would cause plant rot and subsequent death. The lighting system produces light in an oblong pattern, so that light is not wasted on the pathways. The amount of light applied is measured by comparing light received by an exterior light sensor and light sensors in each growing area. The computer turns on the lighting system, until the amount of light applied reaches the required level for maximum growth.

Air samples are collected (15 min intervals) and passed through a gas analyser to assesses the level of CO_2 in each greenhouse, compared with pre-set levels in the computer, and if additional CO_2 is required, this is applied to each orchid table though micro tubes.

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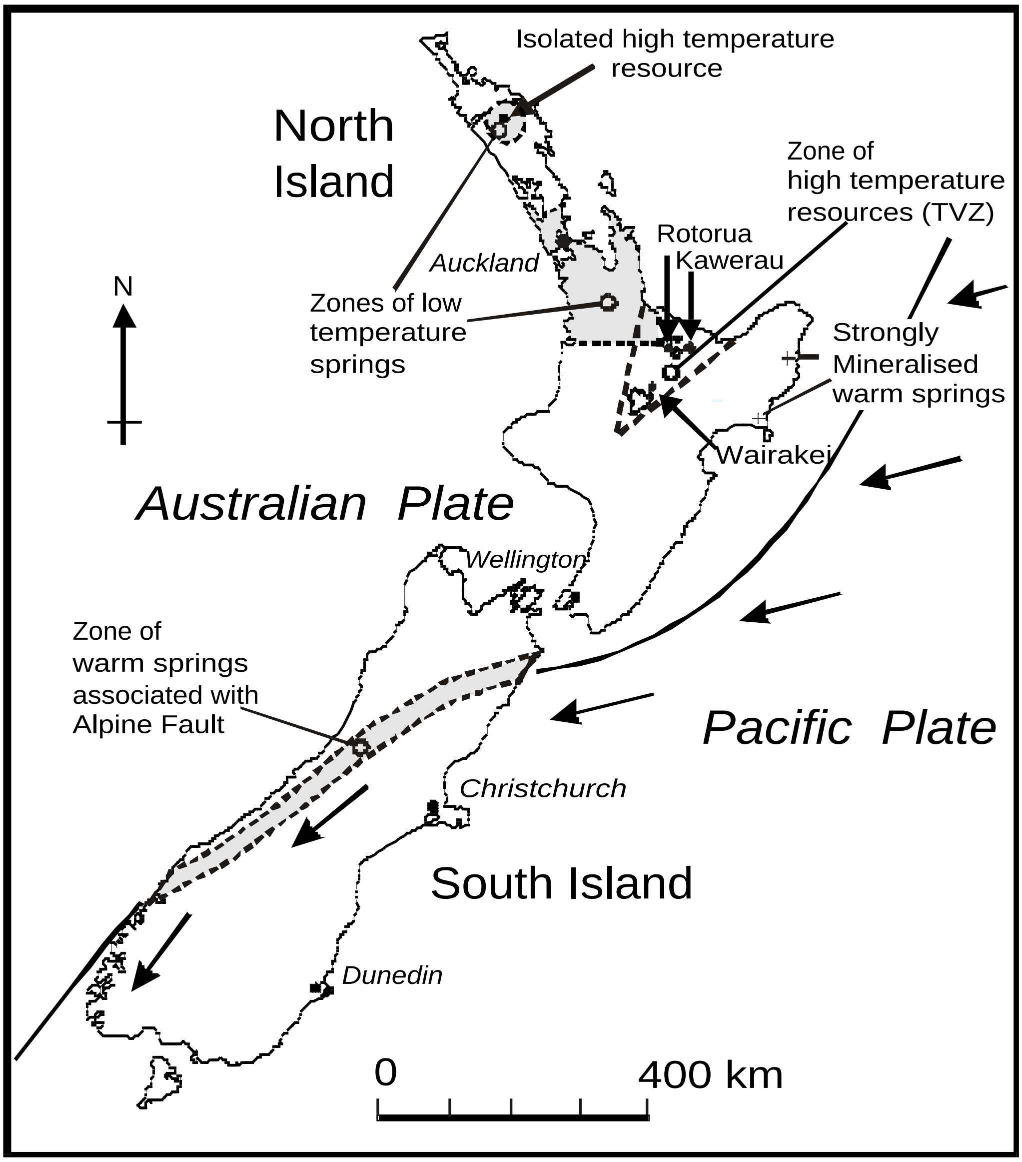

Fig. 1. Map of New Zealand showing distribution of low- and high-enthalpy geothermal resources.

Fig. 2: Indoor swimming pool at the Aquatic Centre, Rotorua.

Fig. 3: Mineral Pools, Polynesian Spa, Rotorua (temperature 34-44°C).

Fig. 4: Timber stacked ready for geothermal drying, Kawerau.

Fig. 5: Reconditioning of geothermally dried timber, Kawerau.

Fig. 6: Green peppers growing in a geothermally heated greenhouse at Kawerau.

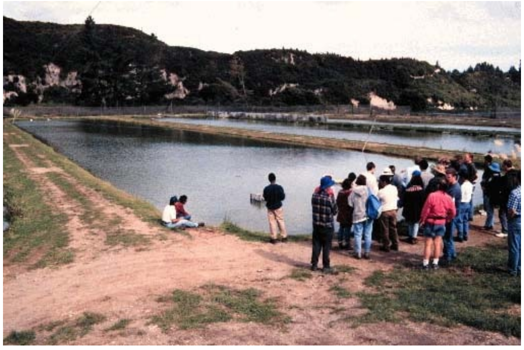

Fig. 7: Geothermally heated outdoor pools containing tropical prawns, Wairakei.

Fig. 8: Hot water intake and plate type heat exchanger at prawn farm, Wairakei.

Fig. 9: Larval breeding tanks at Wairakei prawn farm.

Fig. 10: Nursery ponds at Wairakei prawn farm.

Fig. 11: Harvested prawns, Wairakei prawn farm.

Fig. 12: Orchid *Phalaenopsis*

Fig. 13: Geothermally heated greenhouse with potted orchid plants, Wairakei.

Fig. 14: Main heat exchanger at Wairakei orchid farm.

Fig. 15: Forced air heat exchanger at Wairakei orchid farm.