Cascaded Use of Geothermal Energy

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Abstract

With a greater awareness of environmental issues, there has been a move. towards more efficient use of the world's natural resources. Until recently, little use has been made of the heat contained in the geothermal water following steam separation although the heat energy contained in the separated water can be greater than that contained in the steam. The cuwent trend of installation of binay plants to produce electricity is the first major utilisation of this heat. Downstream of binay plants, utilisation of the available heat energy is best accomplished by directly using the heat content of the water. One of the main reasons why this has not been practised in the past is the problem of silica deposition. Research has shown that this problem can possibly be alleviated by either treatment of the water to stabilise the silica, or total removal of the silica. One possibility could be to temporarily stabilise the silica and extract the heat through a heat exchanger thus transferring the heat energy to a fluid that will not cause scaling problems.

As well as the heat energy, the separated water also contains a large number of dissolved minerals. Research is actively been pursued to produce a commercial product from the silica, and once this has been removed, the possibility exists to extract other commercially useful minerals. Possibly, the most valuable constituent is lithium. Technology does not cuwently exist at a commercial stage to accomplish lithium recovery, but laboratoy work has shown that it is at least feasible. Similarly, the water contains quite large quantities of boron and laboratoy tests have shown that this can also be extracted. Another possibility is the extraction of arsenic. Although of negligible value, it has the advantage of reducing the environmental risk. The major component ofgeothermal water is common salt, and it could also be economically extracted. . Other minerals for possible extraction are gold, silver, and potassium chloride, and once all of these minerals have been extracted, it may be possible to use the water itself for low grade uses. As well as useful minerals, the geothermal water also contains environmentally sensitive elements and compounds. The two principal options that exist for the disposal of the water are reinjection and surface disposal. Although reinjection was seen initially as useful for maintaining reservoir pressure, experience at a number of geothermal fields around the world has suggested that the beneficial effects of reinjection are outweighed by the detrimental effects due to cooling of the reservoir. Currently, reinjection is practised mainly to avoid the environmental issues connected with surface disposal. Treatment of the geothermal water to extract the environmentally sensitive components becomes much more feasible if silica has been previously removed. Therefore, if mineral extraction is envisaged, continuing disposal of the treated waste water to the surface could be possible. Since many of the mineral extraction processes, heat uses and environmental controls are inter-related, future planning should embrace the concept of a total, integrated development of the resource.

1.0 INTRODUCTION

The introduction of the Resource Management Act and a shift in attitudes towards New Zealand's indigenous resources has prompted a move towards a more complete, and therefore more efficient, use of geothermal resources. (eg Harper et al 1992). This trend is reflected worldwide. With a few exceptions, development of high temperature liquid geothermal resources has consisted primarily of extracting steam for electric power production without regard to the use of the available heat energy produced in the process. For instance, for many years at the Wairakei geothermal field, nearly 1200MW of heat energy was extracted to produce 157MW of electricity. Secondary uses of the waste heat have now been installed there and others are being considered.

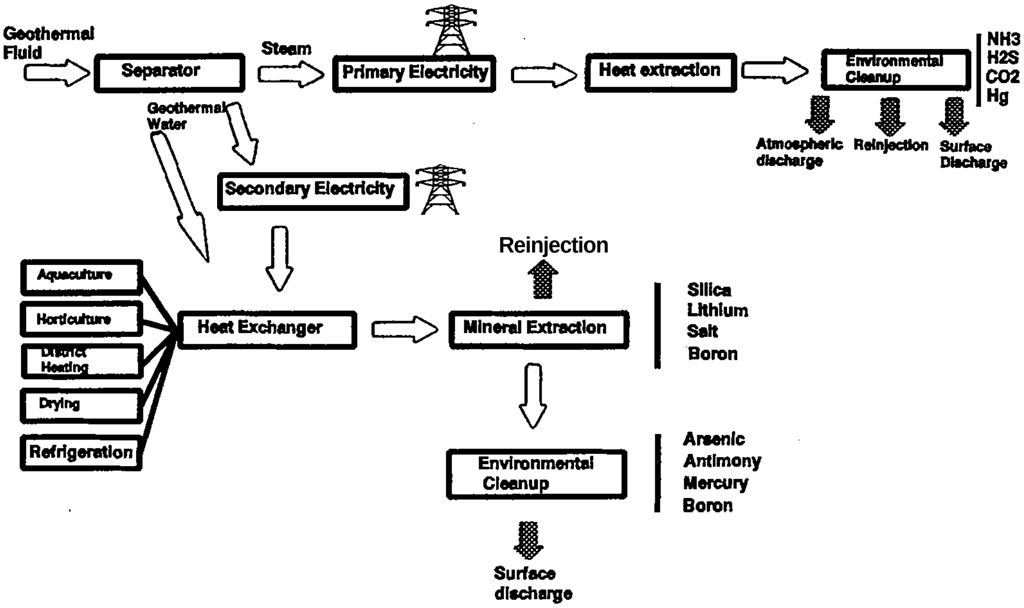
As well as its energy content, the geothermal fluid also contains a large number of dissolved minerals.

Many of these, such as mercury and arsenic, are currently considered as pollutants, but geothermal fluid could equally well be considered as ***sources*** of a number of useful minerals. Indeed, with suitable treatment, the geothermal water itself could be considered as a source for irrigation or other uses.

Thus a more complete use of the resource could still extract steam for power production, but then continue to "cascade" resource use to more effectively utilise the heat energy and mineral content of the geothermal fluid. Figure 1 shows a schematic of one such possible cascaded use.

Figure 1

Cascading Use of Geothermal Fluid



Currently, technology does not exist for some of the processes described in Figure 1, and others may not be applicable. However, some of the processes are being actively investigated at the moment, and many are already available.

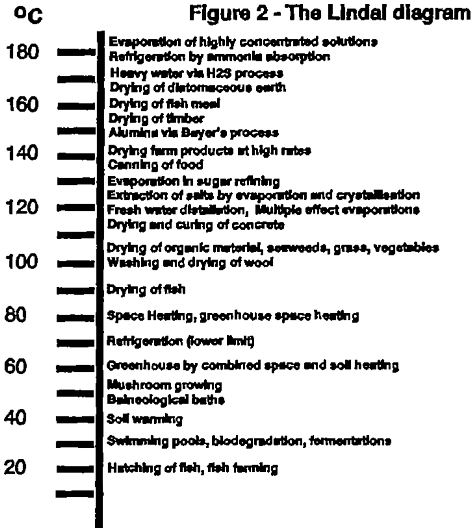
2.0 HEAT ENERGY

Energy is extracted from a geothermal field in the form of a hot water/steam mixture. The heat energy (measured in Megawatts - MW,) contained in this mixture can be calculated with respect to water at ***25°C*** which, for the current purposes, we consider to be the background temperature. As an example, we take a generic liquid dominated geothermal field where the reservoir temperature is 280 "C. The primary electricity production is by normal steam flash. Let us say that the flash temperature is 165 "C and the total flow from the field is 1000 kg/sec. Thus the total heat content of the fluids that are extracted is 1131 MW_H. Of this the 260 kg/sec of steam extracted at the 165°C flash has a heat energy of –690 MW_H or roughly **50%** of the available heat energy. This could be expected to produce around 120 MWe of electrical energy. If all of the separated water is further dropped in temperature to 80°C in a binary generation plant, then a further 268 MW, (or 24% of the total energy available) of heat energy is extracted for maybe 30 MWe of electrical energy. Thus so far, 74% of the available heat energy or 958 MW, has been utilised to produce 150 MWe.

Although the conversion from heat energy to electrical energy in the binary generation plants seems to be very inefficient with about 9 times as much heat energy needed as electrical energy is produced, it is of course governed by the laws of thermodynamics. These same thermodynamic laws also predict that the conversion becomes less efficient when the temperature difference is smaller. Consequently, there comes a point where conversion of the heat energy to electrical energy is so inefficient that better uses can be found for the remaining 26% of the available energy. Use of the heat energy directly can be very efficient and there has been a growing awareness of such uses around the world. The Lindal diagram (Lindal, 1973) is shown in Figure 2 and lists typical process temperatures of possible direct uses.

The Lindal diagram emphasises that the particular use of the heat is dependent on the temperature of the geothermal fluid. At our hypothetical field, it may be more efficient to use the heat energy directly from the water at 165°C rather than use a binary cycle generation plant.

Figure 2 - The Lindal diagram



One of the main impediments to implementing any of these schemes that utilise the separated water is the problem of silica deposition. Silica that is initially dissolved in the water at the high underground temperatures becomes supersaturated and tends to deposit as a scale when the geothermal water is cooled. Consequently, heat exchanger surfaces become fouled, pipes become blocked, and heat extraction processes become very difficult. However, with the increased awareness of the value of the heat content of the resource, together with the movement towards more complete utilisation of the resource, there has been renewed interest in silica scaling research. Some of this research is still at the exploratory stage, but other research has progressed to the pilot plant stage.

Current and past research into methods of silica scaling abatement fall into two general classes:

1. The first approach is to try to stabilise the colloidal silica so that it does not deposit and form a scale. There are a number of ways that this has been attempted.
   (i) The use of dispersants. As yet, these have had rather limited success, although confidential research is continuing both in New Zealand and overseas.
   (ii) The properties of the colloid can be altered by altering the way in which it was formed without adding extra chemicals. With the right circumstances, this can lead to conditions that reduce the scaling potential of the water.
   (iii) Reduction of the pH by adding acid, has been shown to be effective in almost eliminating silica scaling in a number of different experiments
   (iv) Addition of alkali has also been suggested as a treatment for silica scaling. This will definitely be successful, but is very expensive.

2. The second approach is to completely remove the silica from the water. Research in this area has been undertaken in Kawerau and a process patented. Other methodologies are actively under investigation in New Zealaiid aiid overseas, however, at the moment these are

> confidential. This is probably a less attractive option for silica scaling abatement, but is attractive from the mineral recovery aspect. The reason why it is unattractive from a scaling viewpoint is that the silica has to be removed before the temperature is dropped to avoid the scaling during heat extraction, however, when the temperature is subsequently dropped during heat extraction, further silica becomes available for deposition. This is the reason that mineral recovery is placed ***downstream*** of the heat exchanger in figure 1.

Use of the direct heat energy in the separated water is probably best currently achieved by using a heat exchanger to transfer the heat energy to treated fresh water as shown in Figure 1. In this way, although some energy is lost, the silica scaling problems are localised in and downstream of the heat exchanger. This allows special materials to be used in the heat exchanger without the cost of using such expensive materials in the complete heat use installation. For instance, titanium heat exchangers may be indicated if acid dosing is required. Also, if the scaling is localised, then it may be economic to accept the silica scaling and have a cleaning schedule with two cycled heat exchangers.

In summary, there are a number of methods currently available to cope with silica scaling, and research is proceeding world wide on a number of fronts to investigate new and improved technology.

MINERAL EXTRACTION

As the hot geothermal fluid travels underground through the earths crust, it interacts with the minerals present in the rocks. This interaction causes some minerals to be dissolved into the geothermal fluid, and consequently when the fluid arrives at the surface, it contains a large variety of chemical elements and compounds.

Some of these dissolved species are present in very small concentrations, but others are in quite significant concentrations. However, with the very large quantities of water that are produced from the Kawerau geothermal field, even those dissolved species with small concentrations can amount to large quantities on an annual basis.

Silica.

Silica is probably the easiest mineral to "extract" in that it naturally deposits from geothermal waters. Producing a useful silica product with the required purity and properties however, is much more difficult. Nevertheless, there is already a pilot plant for silica extraction at Kawerau. A separate report addresses the issues involved with this extraction plant. Confidential research is also being undertaken at other geothermal fields on the extraction of silica from geothermal water. There are a variety of markets and possible uses for silica and one might surmise that in the future, a large supply of silica could encourage a multiplicity of new markets and uses for this mineral.

Silica extraction plays a pivotal role in any further mineral extraction processes. As mentioned above, silica is the principal component of geothermal fluid that is deposited when the geothermal fluid is cooled. Many subsequent mineral extraction processes will not be possible if there is the likelihood of silica scaling. Consequently, in the overall plan of a cascaded use of the geothermal resource, it should be aimed to extract all of the available silica, and it should probably be the first extraction process.

Lithium.

There is increasing demand worldwide for lithium as it becomes a possible alternative in the manufacture of batteries. Recent world lithium production trends are increasing and price trends are increasing slightly. The principal uses of lithium at the moment are in the production of aluminium, as an additive in ceramics and glass, and as a soap in lubricants.

The value of extracting lithium from geothermal fluids has been realised for some time and research has been carried out in New Zealand over a long period. It is difficult to extract lithium because it behaves chemically very similar to sodium which is in a very large excess. Research into lithium extraction generally relies on one of two general types of technology. The first is a selective absorption on to some type of exchange medium - typically organic resins or clays. The second is to rely on specific chemical reactions which concentrate the lithium by forming sparingly soluble lithium compounds.

Boron.

Boron was extracted from geothermal steam at the Larderello geothermal field in Italy for many years, however, there are no geothermal developers who currently commercially extract boron from geothermal water. The ratio of the boron in the steam phase to that in the water phase is controlled by temperature, with more boron distributing into the steam phase with higher temperature. At typical separation pressures more than 95% of the boron will be present in the water phase. World production and price trends for borax show that here is an increasing production trend and a reasonably stable price trend. Boron is used extensively in NZ as a timber preservative.

There have been some laboratory investigations into the extraction of boron from geothermal fluids. Most of these have been aimed at environmental control, so that although the boron may be entirely or partially removed, it could not be recovered. At this stage, it appears that the best method to recover the boron is to use a boron specific resin which will reversibly absorb the boron. Such resins are known and used scientifically. The economics of the process are not known in detail, but since acid is required to release the boron, the acid consumption and the initial capital cost of the resin will largely determine the economics of this process.

Arsenic

One of the principal uses of arsenic in New Zealand is in the compound copper chrome arsenate (CCA) which is the second common method used in the preservation of timber. There have been a number of research projects aimed at extracting the arsenic from geothermal fluid. However, most of these have not had the recovery of the arsenic as a primary objective. Published work carried out at Wairakei, has shown the feasibility of arsenic extraction by adsorption on to an iron floc. This is the same process as is used for drinking water treatment and for removing heavy metals from mine wastes. The technology is well known and a pilot plant is now under construction at Wairakei to test the feasibility. The arsenic could conceivably be recovered from the waste iron floc sludge, but as yet, this has not been tested. A difficulty is that iron contamination is very undesirable in wood treatment chemicals.

The global price of arsenic has been on a downward trend for the last decade. Most of the world production is as a by-product from mining, and with increasing environmental awareness, replacements are being found for arsenic use.

Caesium, Rubidium.

Caesium and rubidium belong to the same chemical group as sodium, potassium and lithium. As such, they are difficult to remove without contamination by these elements which are in a large excess. Very efficient methods would need to be employed to recover these elements from such a low concentration. Rubidium is similar to caesium in geothermal concentrations.

Others.

The major dissolved component of the geothermal water is sodium chloride, or common salt. This is normally produced in New Zealand by evaporation of seawater using solar energy. The predominant minerals of the geothermal water are probably also best recovered by evaporation, however the possibility exists of using geothermal heat energy instead of solar energy for this evaporation. One of the problems will be the possibility of arsenic contamination from the geothermal water. Potassium chloride is used in fertilisers and also could be a valuable extract.

There are many other elements that are present in geothermal fluid, but generally their concentrations are so low that they need to have a very high price and easy recovery to make their extraction worthwhile. One group of elements that may come into this category is the rare earths. At the moment however, there is little information about the concentrations of these elements in geothermal fluids. Experiments have also been conducted on the extraction of gold and silver from well fluids.

Although very large concentrations of gold (~6 wt%) and silver (~30 wt%) were found in scales deposited in New Zealand wells, the quantity was very small and the process was not economic.

The final mineral to be considered is the water itself. If the major mineral constituents of the geothermal water have been removed, then the water may be suitable for low grade uses such as washing or irrigation, without further treatment. With suitable treatment, the water could even be used as a source of drinking water.

ENVIRONMENTAL CONSIDERATIONS

As well as useful minerals, the geothermal water also contains environmentally sensitive elements and compounds.. After extraction of useful minerals, two principal options exist for the disposal of the water - reinjection and surface disposal. Reinjection was seen initially as useful for maintaining reservoir pressure. However, experience at a number of geothermal fields around the world has suggested that the beneficial effects of reinjection are outweighed by the detrimental effects due to cooling of the reservoir. Currently, reinjection is practised mainly to avoid the environmental issues connected with surface disposal. There is an increasing awareness of the possibility of treatment of the geothermal water to remove environmentally sensitive constituents, which then allows surface disposal of the water. As mentioned above, some constituents, such as arsenic and boron, although being an environmental problem, could be extracted for sale. In these cases, even if the economics of such extraction processes were slightly unfavourable, it could still be economically viable when compared with the costs of reinjection. One important point is that treatment of the geothermal water for environmental control is much easier if silica has been previously removed. It is therefore sensible to include environmental treatment if mineral extraction is envisaged.

The recognised environmental chemical constituents that need to be treated are arsenic, mercury, boron, lithium, and the gases ammonia and hydrogen sulphide.

Arsenic

Arsenic has long been recognised as an undesirable constituent in geothermal waters. There have been many methods described for removal of arsenic from potable waters, however, very few methods have been extended to geothermal waters. Early work relied on the co-precipitation of silica and arsenic when lime was added. As in all succeeding experiments, it was found that oxidation of the arsenic from As(III) to As(V) is a necessary precursor to the reaction. (Arsenic is always in the III oxidation state when discharged from geothermal wells). The experiment showed that 700ppm of quicklime per tonne of water was required to give 80% removal of the arsenic. The process produced a calcium silicate gel that could be dried and used in wallboards or other insulation applications.

The other technology that has been tested on geothermal waters is the adsorption of the arsenic on to an iron floc (Buisson et al 1979). The method was borrowed from potable water and mine waste treatment technology and was proven successful in removing nearly all of the arsenic present. The iron floc was recovered by dissolved air floatation. A large scale pilot plant is currently about to test this technology at Wairakei.

Mercury.

Most of the mercury discharged from the total flow of the geothermal well is concentrated in the steam phase, however some mercury remains in the water phase. Water treatment methods (Handbook of Public Water Systems 1986) are dependent on the form of mercury present and are normally aimed at much higher mercury concentrations of 3 - 16 ppb than that found in geothermal systems where there are ppb levels. At the point of discharge, the mercury will probably be in the form of inorganic mercury - either as a salt or as elemental mercury, although the chemistry of this process is not well understood at the moment. The very large flows to be treated probably prohibit the use of expensive technology such as ion-exchange resins or activated carbon. The removal of silica though, makes these technologies possible if not economic.

Boron

Unlike mercury, most of the boron in the total discharge remains in the water phase during phase separation of the geothermal water. There are no reported extraction processes which have been tested beyond a laboratory scale. More favoured methods are adsorption on to calcium, magnesium or iron hydroxides, but laboratory experiments indicated that only up to 50% of the boron could be removed in this way. Conventional waste water treatment wisdom is that coagulation of lime, alum and ferric sulphate is ineffective in removing boron. Another technique used in the laboratory is solvent extraction, where the boron is extracted into an organic phase separate from the geothermal water phase. This could be possible, but could result in a greater problem from the organic solvents. Certainly one of the most effective ways to remove boron selectively is to use boron specific ion exchange resins. These are successful in removing up to 98% of the boron and releasing it again on addition of acid. However, the capital cost of the resin is high, and the operational costs would also be expected to be high with large quantities of acid being required. Once again, silica has a detrimental effect on the resin and would need to be removed before the boron extraction phase.

Hydrogen Sulphide

Once again, most of the hydrogen sulphide originally present in the total discharge from the well, is concentrated into the vapour phase during steam separation. Hydrogen sulphide is oxidised slowly by air to either sulphur or sulphate ion. Commercial processes for removal of hydrogen sulphide have been installed in many geothermal power plants. These however, are for removal from the vapour phase and are designed for much greater concentrations than are found in the water phase.

Reference:

Harper, R.T., Thain, I.A., Johnston, J,H. "Towards more efficient use of geothermal resources" In Industrial Uses of Geothermal Energy, Iceland 1992.