MINERAL RECOVERY THROUGH GEOTHERMAL DESALINATION

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ABSTRACT

A recent review of mineral content in the geothermal waters of the Taupo Volcanic Zone has estimated gold content at over 20 parts per billion and silver content at 2,000 ppb (Simmons *et al.*, 2016). Wells at Mokai and Rotokawa are estimated to be extremely rich and could produce 680-7500 kg Au/year. Lithium production from geothermal and petroleum brines are already accepted technologies but the current production techniques are not integrated seamlessly into a geothermal energy cascade. We propose to use a variant of multi-effect-distillation (MED) technology to close this gap. We present a setup that is currently on trial for caustic soda recycling from spent liquor recovered in the Bayer process for alumina production (Rahimi *et al.*, 2016).We propose to use the same technology to concentrate the brines for mineral harvesting.

The MED technology is better known in seawater desalination due to its low electrical energy consumption, low operation cost, high thermal efficiency and compactness. MED is a process that is suitable for use on a range of water types including brackish, seawater and industrial process water requiring a thermal energy source to drive the distillation process. We propose to use the waste heat stream of the geothermal power station to power the MED process. In such a process, the process feed is heated in the first stage by the geothermal waste heat stream, thereby vaporising the feed under reduced pressure. The vapour from the first stage is then condensed in the next successive stage and giving up its latent heat to drive the evaporation of further amounts of process feed. This process is repeated across each effect (stage) within the plant, increasing the degree of internal energy recovery. Economic operation is commonly considered to be viable in the temperature range between about 65-100°C.

1. INTRODUCTION

Geothermal energy is a sustainable energy source with an inconspicuous aboveground footprint. Its climatic, diurnal and seasonal independent characteristic allows for a quantifiable, reliable and extremely stable energy supply, making it a perfect match to the energy intensive process of demineralization of saline water. However, to date no such plant exists although economic viability studies clearly show the technology to be competitive even in non-volcanic settings such as the Western Australian Sedimentary Basin (Christ *et al.*, 2017).

Several contributing factors can be identified for this situation. In deep geothermal systems, drilling costs constitutes the lion's share of the overall capital cost. They are primarily determined by well depth rather than the geothermal fluid flow rate. Thus, the options of pre-test with smaller pilot plants to reduce initial capital costs are very limited. Test wells to determine the local geothermal characteristic are, for exactly the same reason, relatively expensive. These cost hurdles are most often reflected in the paucity of available geological database prior to well field development, resulting in relatively high uncertainties in terms of characterising the geothermal sources, particularly with regards to the prediction of temperature, flow rate, and geochemistry. Consequently, the need for risk management invariably mandates the preference for conventional as opposed to advanced systems even when highly prospective geothermal resources are available.

This obstacle for the development and deployment of clean geothermal power technology is, most easily overcome when no competing solution exists to tackle an entirely new engineering challenge. Additionally, we must look for an industry where the risk of extremely large capital investments upfront is mitigated by the assurance of large capital gain from the investment. This is the case for the mining industry where block caving methods constitute the largest upfront capital investment of hundreds of millions of dollars. Another large capital investment upfront is required for the offshore oil industry. We claim that in both industries geothermal desalination techniques have a promising role to play. In the case of the oil industry the technology can be used to support enhanced oil recovery by low salinity water flooding. This contribution focusses on the opportunities of geothermal technology in the mining sector.

The challenge here is to provide access to deeper mineral resources while at the same time provide an environmentally safe future for the mining industry. The key idea of our proposition is to harvest minerals out of deep geothermal fluids. If it is indeed possible to harvest minerals out of the fluids, then the waste product would be distilled water instead of the large quantity of chemically treated mine wastes produced by classical mining technologies. As no established technology exists to date Geothermal technologies are on equal footage with other technologies and owing to the remote conditions their energetic advantage can overcome the major economical challenge for their development. The lowest risk in developing the new technology is in situations where geothermal sources are near the surface and mineral deposits are known to be associated with the geothermal systems. Such a situation is encountered in the South Pacific volcanic islands where large scale mineral deposits are well known.

2. MINERAL SYSTEMS IN FIJI

Gold, Copper Bauxit ore deposits are very common in the South Pacific region and are of high economic interest. Yet from a societal aspect they currently return very little to support the infrastructure of these islands. This is mainly due to the fact that the high cost of mining is borne by multinational companies with little connection to local communities. Costs are driven by the immense amount of energy needed for operations. For example, the Vatukoula Gold mine in the northern part of Viti Levu needs 20,000 liters of fuel per day for mainly rock crushing. Not only is this very expensive, it is also environmentally problematic because of the high CO_2 production caused by burning of the fuel. Another undesired side effect of conventional mining operation is that after the exploitation is terminated, the infrastructure is of little use to local citizens/communities resulting in high rates of unemployment and barren and desolate landscapes.

2.1. Bauxite mining

An example is the Bua Bauxite mining in Vanua Levu, the second largest island of the Fijian archipelago. The Bua mine is a large mine located in the northern part of Fiji in Vanua Levu. Vanua Levu represents one of the largest bauxite reserves in Fiji and one of the largest in Oceania, having estimated reserves of 1 billion tons. Bauxite ore is currently mined from 408 hectares of prospective zones in the Nawailevu area in Bua and part of the Naibulu East area in Macuata. The Nawailevu mine has ceased operations and the site is undergoing progressive rehabilitation with a reforestation program on the mine site of 160,000 pine seedlings. The Bauxite is sold at current price of $50 US per tonne and shipped overseas. No attempt is made to process the ore locally. The return for the local land owners and the Fijian population is a future generation fund of $600,000 that has been paid to the landowners for access to 20 million tons of bauxite to be mined in the future.

We posit that the return for the local population in terms of revenue and employment could be much enhanced if a local alumina refinery can be built. Moreover, the refinery could tap into the local clean geothermal energy resource and become the first green mine operation worldwide, where all energy comes from a renewable source and the waste product is distilled water which can be used for rehabilitation.

The technological innovation for this possible green mineral future is a novel low-grade heat driven process to re-concentrate process liquor in alumina refineries (Rahimi *et al.*, 2016). It couples flash and falling film evaporation, fed by a low-grade heat source, to recover heat and concentrate process liquor. An alternative device using plate type heat exchangers instead of the falling film has been built and is currently tested in our laboratory in UWA in collaboration with a large Australian based Alumina refinery.

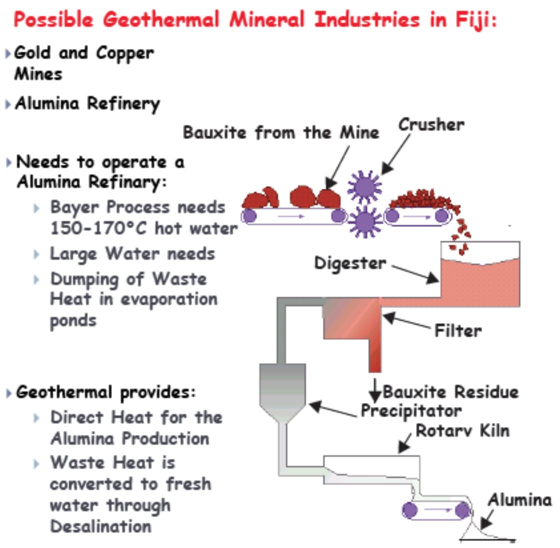

Figure 1: Geothermal energy provides multiple opportunities for mineral recovery and processing. The alumina refinery is an ideal example of where the same geothermal heat can be used twice.

While the novel technology is not yet available as an industrial application Figure 1 shows possibilities of using conventional technologies using the provision of hot water from geothermal systems for the Bayer Process and subsequent distillation falling film evaporators for the concentration of the liquor from the waste heat stream.

2.1. Gold Mining

Another example is the Vatoukola gold mine in north Viti Levu, the largest Fijian Island. The Vatukoula Gold Mine is an underground mine with an operational history of over 75 years. The Mine is located within the Tavua Basin, situated within the caldera of the Tavua volcano. The mine operates within three Special Mining Leases which cover a total area of 1,255 hectares. There are nine shafts in the Mine, but only four are being used because five shafts are needed for ventilation; the Smith & Phillip Shaft for hoisting ore, the Cayzer Shaft for men and materials and a Decline Shaft for access for the rubber tyred mine fleet. The Vatukoula Gold Mine is currently both an open pit and underground operation, however in the medium-term it will become predominantly an underground mine. At the Mine site there is a seven hundred thousand tonne per annum processing facility, which includes crushing, grinding, flotation, roaster, CIP and tailings dams. The mine has had a challenging history as the shafts have been driven ever deeper underground and the geothermal systems feeding the mineralization lead to ambient temperatures in excess of 60ºC. Therefore, the costly operation of the ventilation shafts and the extreme conditions counterbalance the high ore grade (Figure 2) which has so far supported the long life of the mine. No current technique exists to extract the gold from the high grade directly. The rock still has to be crushed and ground and harvested conventionally. In 2006 owing to fluctuation in the gold price mine the Mine shut down due to low price of gold and the high level of capital required to sustain the mining operation. The mine's closure left 1,760 former employees and local businesses without work and was a huge blow to the social system in Fiji. The mine re-opened in April 2008 and is currently producing gold, albeit now on a smaller scale.

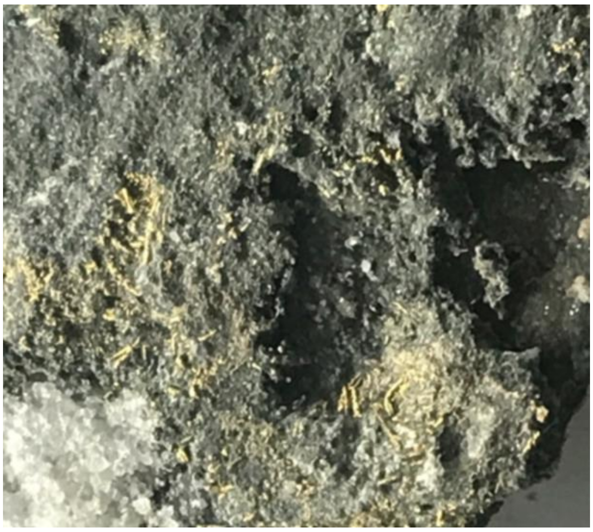

Figure 2: Vatoukola high-grade gold ore where quartz minerals and gold needles can be seen in the porous basalt.

Since the mine is operating in an active geothermal system a different approach to the mining operation could open new avenues for future mining in general. Aside from the possibility of production of geothermal electricity from the volcanic source (similar to Lihir in Papua New Guinea) the mine could become a test case for another novel geothermal mining technology briefly discussed next.

3. GEOTHERMAL INNOVATIONS FOR MINERALS

3.1. Sorption Chillers for Mine Ventilation

The technology is based on replacing electrically driven Vapour Compression Chillers with heat driven Sorption Chillers (refrigerator/freezer). The technology is scalable up to 100's of MW thermal cooling capacity to service cooling needs for large commercial buildings, including universities, hospitals, hotels, airports, data and shopping centres. Hot geothermal water as the principal power source is the most energy efficient means of heating and counterintuitively also cooling.

The use of thermal chillers is widespread in tri-generation facilities which supply electricity and air conditioning to intermediate size settlements in hot climates: e.g. in the Middle East,Gardens Residential Complex, Jumeirah Islands, Discovery Gardens, Palm Jumeirah Trunk, Shaikh Fatima Tower, Shaikh Zayed Road, Rolex Building, Emaar District Cooling, Emirates District Cooling. Even in cold climates the cooling technology has been used with great effect such as in Norrenergi AB providing district heating and cooling service in Solna, Sweden with total cooling capacity of approximately 25 MW thermal, serving 23 buildings. A storage tank of 6,500 m^3 buffers the system with a delivery temperature of 7^{o}C and a return temperature of 16^{o}C. The total length of the pipework is approximately 5 km.

These examples show that the economically and energetically superior chilling technology has made a breakthrough only for extremely large installations. Such applications can be engineered appropriately to provide a convenient heat source (most often waste heat) and sink at scale next to the cooling service. However, Ab(d)sorption Chillers for common refrigeration only have found a niche market for camping and off-grid uses. This is because of the comparative convenience of the electrical refrigerators, displacing the gas driven refrigerators in the beginning of the last century.

It is hence not astonishing that the breakthrough of using off-grid capable Absorption Chillers for freezing is yet to come. The possibility has been explored in a bespoke setting to provide ice for an ice museum in Chena Alaska, where an approximately 80^o C hot geothermal spring drives an absorption chiller for providing the ice for the museum.

The refrigeration technology can be illustrated schematically (Fig. 3) as being identical to its electrically driven sibling, the main difference is the use of a thermal compressor (thermochemical) instead of an electric compressor. A small source of electricity is still required for circulating the chemicals but the pumping power is minor and can be provided by an off-grid PV system or a small generator.

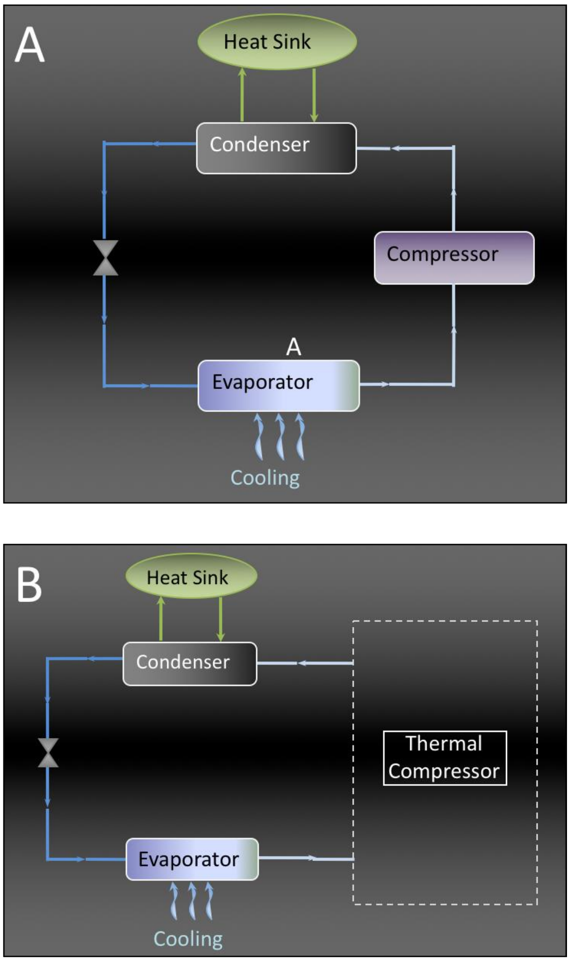

Figure 3: Conventional Mechanical chillers (A) versus Sorption chillers (B). (Graphics by Final Year student Christopher Tan).

Sorption Chillers have fewer moving parts, are quiet and more robust than mechanical compressors. This is another reason for making them an ideal fit for installation in remote mine sites. The need for technical maintenance is much reduced.

Various chemicals can be used for the thermo-chemical evaporation cycle. At the lowest temperature solid compounds such as silica gel or zeolites can be used to adsorb and evaporate distilled water. Hence these chillers are called ***Ad**sorption Chillers*. At higher temperature closed loop

Lithium-Bromide or Ammonia-Water solutions are used to absorb and evaporate distilled water. Hence these chillers are called ***Ab**sorption Chillers*. Figure 4 shows an adsorption chiller that can utilize the water in the deep mine shafts as an energy source. The first author is an inventor on the patent.

Figure 4: 45 RTon commercial four-bed adsorption chiller, US Patent US6490875, Singapore Patent 82589

3.2 Mineral Recovery through geothermal Desalination

The most significant opportunity for the future of the Vatoukola gold mine is currently on trial for a low-grade heat driven process to re-concentrate process liquor in alumina refineries. We propose to use the same technology for concentrating geothermal brines with high gold content. This could replace the entire conventional suite of gold recovery discussed earlier and indeed herald a new clean future for mining. While the temperature level at deep shaft conditions and the gold in solution is conceivably not high enough for economic gold production by brine distillation the problem can be easily overcome. The solution lies in the fact that gold solubility in geothermal water is an exponential function of temperature and the construction of a geothermal power station with deep wells could not only provide the necessary power for the mine operations but also give access to much richer deeper resources that can never be tapped by conventional mining techniques.

The new technique that is currently on trial is a variation of one of the most mature and market available technologies known as Multi-Effect-Distillation (MED). In MED systems, a series of evaporator effects generates water at progressively reduced temperature and pressure, whereby the freshwater vapour generated in one effect forms the heat source for the subsequent effect. Because most of the initial input energy is carried over by the freshwater vapour, this enables a high internal energy reuse and a correspondingly large production rate. The repeated process terminates when the cold end temperature, represented by the cooling source, is approached. Figures 5 shows a technology that is currently on trial for caustic liquor concentration.

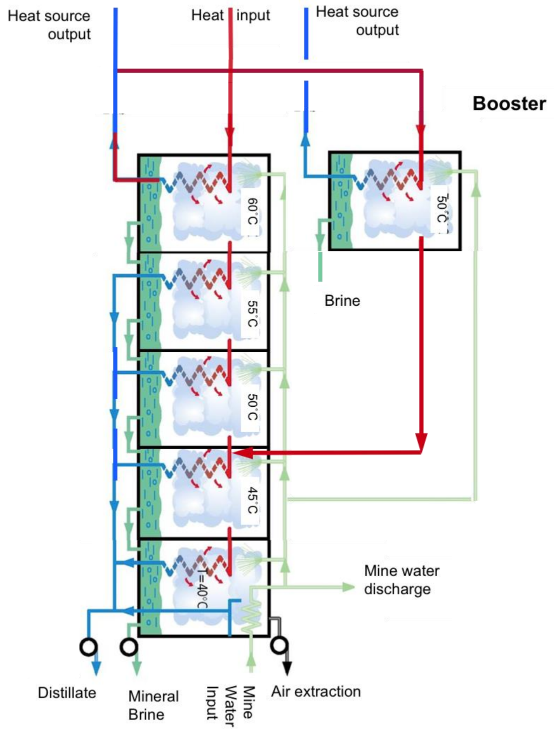

Figure 5: International, PCT/AU2011/00768 "A Desalination Plant"; Inventors: Hui Tong Chua, Xiaolin Wang, Klaus Regenauer-Lieb.

4. CONCLUSIONS

Geothermal technologies presented here can revolutionize the Mining Industry and lead to a paradigm shift in future mining. The technology can as such be classified as a disruptive technology. First attempts are already successful such as harvesting Lithium out of geothermal fluids and Petrolithium out of coproduced water in the Petroleum industry. This approach could be enhanced by targeting deeper resources and drilling specifically for deep igneous fluids. The high mineral concentrations in these fluids could be condensed and extracted and replace the current energy intensive mining, rock crushing and chemical leaching technologies, which are harmful to the environment. Our proposition can displace conventional energy intensive extraction, crushing, grinding, floatation, chemical leaching, tailing pond and mine wastes by a simple geothermal doublet. The waste product from this new technology is electricity and distilled water which can be used to support local communities. In addition, the proposition fits seamlessly into the 'Geothermal Cities' concept proposed in our companion paper in this volume by Sommer et al. (2018).

ACKNOWLEDGEMENTS

This project is part of a portfolio of projects to develop a clean geothermal power solution for the South Pacific. The ultimate target is to integrate multiple uses of naturally available geothermal heat for electric power, cooling solutions and providing fresh water and other direct heat uses to local communities. This project is a contribution to the SRT funded by USP and the IGD fund from UNSW, Sydney as part of UNSW global mission to support the collaboration and student training in the South Pacific.

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