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Valorization of Olkaria Brine Resources for Secondary Power Generation

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ABSTRACT

Geothermal two phase mixture flow reaching the surface consists primarily of a significant brine constituent of 50 - 90 % by mass, but only 4% by volume; from another point of view, the volume in the 2 phase pipes is mainly of the steam component, since density of steam is about 80 times less than that of brine, therefore occupying 80 times more volume. In Olkaria, the steam component from well discharge constitutes only 10 - 50 % by volume. The separated steam is transported across the field to be utilized for electricity generation. The separated brine resource still contains extractable energy, but is currently left unused [estimated total separated brine today is about 1,500 t/h * brine enthalpy [(160 – 220) KWh/t = 330 MWt]. Once it is recovered at 6% efficiency, there would be new and free 20 MWe without the need for additional drilling. As development of Olkaria fields progresses beyond the current 200 MWe to over 600 MWe from the steam component only, additional brine resources will be disposed by the developers abundant with recoverable energy. Methods and approaches of utilizing this readily available energy have been employed for a limited scope of direct uses, while the majority is re-injected back into the reservoir separately. Expensive ORC machines exist to utilize the energy in electricity generation. EGSSS technology presents another solution to the problem of wasted energy. Separated brine is flashed for the second time in controlled conditions to get additional steam and leave the brines for reinjection.

1. INTRODUCTION

Hot separated brine is a significant component of well discharge at Olkaria fields. OEPF is a field of high enthalpy with practically no reinjection for over 30 years, and the surface discharges have been getting steadily higher steam fraction. The discharge is now almost of dry steam (> 90 %). In the adjacent ONEPF hot separated brine flow is a significant part of the discharge from the wells (50 – 30 %). At the domes field the deeper wells drilled there tap mainly in the liquid reservoir with flashing happening as the fluid rises to the surface. At the surface a 50% brine discharge is common. The deeper wells commonly achieve significantly higher discharge pressure and hence higher separation pressure schemes have been employed more recently. At the westerly field (OWPF), Ormat installed binary machines utilizing both steam and brine resources since 1998. This plant has been increased to over 110 MWe capacity at present.

In the past, the main focus of the KenGen developers was the fear of drastic pressure drawdown and the consequent chain of events that has dominated their insistence to re-inject hot brines after separation. The chemistry of these brines is well understood. It is for instance well argued that it is unlikely to affect the reservoir so drastically to lower reinjection fluids to about 135 – 140 °C (Kizito, 2010). It is in no doubt now that separated hot brine resources are in abundance in size and their economic value to the developers at KenGen. It is an economic issue that must be looked at. It is a business issue that must be evaluated keenly. It is a technical issue that has been on the table for too long now. The new 280MWe plants means significant extraction from the liquid fed part of the reservoir and the idea of literally squeezing out the last drop of energy out of the well discharges has never been important. Reinjection as is presently practiced at Olkaria is not the most beneficial from an economic point of view. Useful surface energy is being returned back to the earth without getting a benefit out of it. A good compromise between extraction and reinjection conditions needs to be reached.

This paper is primarily focused on exploring the value of the hot brines reaching the surface, which are currently disposed by the developers at Olkaria, and to evaluate strategies in which this readily available resource could be converted to new and free energy ready for conversion.

2. GEOTHERMAL RESOURCES AT OLKARIA

A total of 40 new wells will be connected to conventional flash power plants at the KenGen concession in 2014. An additional 15 new wells would be connected to wellhead units in the coming months. The total steam production would be 60 % by mass of total geothermal 2 phase mass extracted from the field. The separated brine resources are typically between 150 – 175 °C and therefore a delta T= (10 – 25) °C is possible mainly at enthalpies in the range of 160 – 220 KWh/t. This ensures a safe limit of about 5°C of the recommended reinjection temperature for avoidance of silica scaling risk.

The initial developments at Olkaria involved either dedicated separators at each well or shared separators by two or three wells close to each other. In the 280 MWe developments, the separation process is shared among a number of wells so that for each of the 140MWe with approximately 20 wells, the fluids will be separated at only 3 separation stations. The design itself presents a great opportunity for utilization of the consolidated hot brines available at the separator stations at same conditions. The separators are however designed to allow full reinjection after separation processes.

The benefits of mass reinjection into the reservoir is understood and is not contradicted or demeaned in this work but rather full utilization of mass extracted from the reservoir is advocated. Separated hot brines can be utilized within the safe limit of silica deposition. Silica polymerization has been extensively studied at Olkaria and its limits are now well understood.

For the remaining plants, separated hot brines are usually directed to reinjection and direct use sites soon after separation. It is both easy and convenient to tap midway these pipelines and utilize these energy resources for additional electricity generation.

2φ flow becomes saturated conditions of steam and brine after separation process:

Table 1: Saturated conditions of steam and brine post separation

Property		Metric		Standard	
Temperature (T)		155.00	°C	311.00	°F
Pressure (P)		5.4350	Bar	78.828	psi
Density	Saturated Liquid (ρ_f)	912.28	kg/m^3	56.952	lb/ft^3
	Saturated Vapor (ρ_g)	2.8863		0.18019	
Specific Volume	Saturated Liquid (v_f)	0.0010962	m^3/kg	0.017559	ft^3/lb
	Saturated Vapor (v_g)	0.34646		5.5498	
Enthalpy	Saturated Liquid (h_f)	653.79	kJ/kg	281.08	Btu/lb
	KWh/t	181.61			
	Evaporated (h_{fg})	2098.0		902.0	
	Saturated Vapor (h_g)	2751.8		1183.1	
Entropy	Saturated Liquid (s_f)	1.8924	kJ/kg-K(mayer)	0.45199	Btu/lb- °R
	Evaporated (s_{fg})	0		0	
	Saturated Vapor (s_g)	6.7926		1.6224	

2.1 Options for energy recovery

Separated hot brine still contains extractable energy (160 – 220 KWh/t). There are two considerations that should be observed when thinking about the utilization of this energy resource.

First is the risk of scaling to surface equipment and also in the wells reinjecting into the reservoir. Deposition of scales at the reservoir potentially has detrimental effects since fractures, pores and other conduits that allow the fluid to flow into the well may be either completely clogged or severely compromised.

The second factor is the possible opportunity cost for either non-reinjection or reinjection at lower temperatures. These must be evaluated as reservoir specific since reservoir conditions are not universal. Seldom would you find reservoir conditions identical from one area / field to another. However, lessons can be drawn from previous experiences in different fields.

The avoidance of adequate water reinjection to reach overall mass balance conditions has several chain effects that may prove detrimental to the entire development. This has many worldwide examples and it is essential for sustainable production, especially in Continental land zones like Olkaria. The risks are clear:

- Rapid drying of the reservoir,
- Pressure drawdown is increased, and
- Overall production becomes unsustainable.

In Olkaria I it is a known fact of the effect of lack of reinjection, hot or cold; it has been observed for the past 35 years that no reinjection has resulted in 30 bar drawdown and that steam fraction increases from 60% to almost 90%. Fortunately now there is no longer the fear of rapidly cooling the reservoir that dominated prior thinking. Late injection into OW-R3 located infield has fore-instance resulted into better performance of nearby wells OW-32 and 29-30 after nearly ten years gap to initial breakthroughs.

Energy recovery options that may be considered for the development at Olkaria may primary follow two paths: either ORC technology utilizing brine resources separated from the steam component or EGSSS technology involving a second flash of separated brine for additional steam to be used with the existing or additional generators or both.

Brine resources available at Olkaria after the development of the current 280Mw project stand at about 1500 t/hr considering the scaling limit of 140 °C. Commonly achieved conversion efficiency of ORC machines gives new and free 20MWe for the four different fields. It is to be noted here that installation of ORC machines is generally expensive and time consuming. A project of this magnitude is estimated to cost about $75-80 million and takes approximately 3-4 years to complete. Table 2 shows available resources per field and presents possible generation by ORC technology at 6% conversion efficiency.

Table 2: Valorization of brines at Olkaria per field using ORC technology

Field Sector	Brine Flow (t/hr)	Brine Enthalpy KJ/Kg	Separation Temp (°C)	deltaT (140°C)	MWt	ORC Option Mwe (6% eff)
OLK1	13	640	152	12	2.31	0.14
OLK2	164	640	152	12	29.16	1.75
OLK1AU	529	790	186	46	116.09	6.97
OLK4	814	799	188	48	180.66	10.84
	1520				**328.22**	**19.69**

On the other hand, presently re-injected brines may be further flashed either at common separation stations or along the re-injection pipelines to generate so called secondary steam to be either directed to existing plants or new generating units altogether. This may actually supply steam readily to replace the need for make-up drilling or steam necessary for auxiliary equipment in existing plants and therefore availing more steam for conversion. After these brines are flashed for a second time they may be re-injected into the reservoir. This presents a quick and cost effective option for energy recovery from the brine while still ensuring that it is re-injected back into the reservoir. The EGSSS technology (Navas, 2006) may be employed for an estimate of only $15 for a total possible generation of new and free 130MWt energy which converted at 12% giving 16 MWe of electricity. The added advantage of this method is that it may be implemented within a period not exceeding 12 months.

Table 3 shows the scenario possible to achieve with this option with 168 t/hr of additional steam extracted by flashing the brines resources available at the Olkaria field after the 280MWe plants come online.

Table 3: Valorization of brines energy at Olkaria field using EGSSS technology

Field Sector	Steam flow (t/hr)	2nd flash = Added Steam (t/hr)	MWt (777KWh/t)	EGSSS Option MWe (12% eff)
OLK1	430.9	20.52	15.94	1.91
OLK2	633.68	30.18	23.45	2.81
OLK1AU	1354	64.48	50.10	6.01
OLK4	1108.2	52.77	41.00	4.92
	3526.78	**167.94**	**130.49**	**15.66**

2.2 Economic Valorization

Simple economics of the two methods of energy recovery are shown in Table 4 and 5. The first scenario is to consider that a feed-in tariff is possible for commercial generation from either ORC or EGSSS. However, new tariffs may be negotiated for expected additional power into the grid. But a more realistic possibility is for the utilization of the additional power within the framework of existing power plants. This may be either utilizing some of it to run plant auxiliaries and to evacuate the remainder along with the generation from existing power plants. The 280Mwe plant has the cheapest tariff and therefore is appropriate to be used here to estimate a most pessimistic case. In the case that the operators choose the more optimistic feed-in tariff plan or fail to achieve it and negotiate a completely new tariff, it should be expected to fall in-between the two cases considered here.

Table 4: Economic valorization for the ORC option

Field	MWe (6%)	Revenue Scenarios_ORC option Option 1: Feed-in ($8.8 cents/Kwh)	Option 2: 280 tariff ($7 cents/Kwh)	Annual Revenue Option 1 (USD)	Annual Revenue Option 2 (USD)
OLK1	0.14	12.20	9.71	106,895.36	85,030.40
OLK2	1.75	153.94	122.45	1,348,526.08	1,072,691.20
OLK1AU	6.97	612.93	487.56	5,369,307.68	4,271,040.20
OLK4	10.84	953.90	758.78	8,356,159.33	6,646,944.92
TOTAL	**19.69**	**1732.98**	**1378.51**	**15,180,888.45**	**12,075,706.72**

Table 5: Economic valorization for the EGSSS option

Field	MWe (12%)	Revenue Scenarios_EGSSS option Option 1: Feed-in ($8.8 cents/Kwh)	Option 2: 280 tariff ($7 cents/Kwh)	Annual Revenue Option 1 (USD)	Annual Revenue Option 2 (USD)
OLK1	1.91	168.36	133.92	1,474,844.53	1,173,171.79
OLK2	2.81	247.59	196.95	2,168,901.10	1,725,262.24
OLK1AU	6.01	529.03	420.82	4,634,345.55	3,686,411.23
OLK4	4.92	433.00	344.43	3,793,044.12	3,017,194.19
TOTAL	**15.66**	**1377.98**	**1096.12**	**12,071,135.30**	**9,602,039.44**

3. CONCLUSIONS

In Olkaria, the steam component from well discharge constitutes only 50 - 10 % by volume. The separated steam is transported across the field to be utilized for electricity generation. The separated brine resource still contains extractable energy (160 – 220 KWh/t) but is currently left unused and/or re-injected into the reservoir. Two options were considered for the recovery of the brine energy available at the field. The ORC option is expected to require huge frontal cost rendering the option uneconomical. The EGSSS option utilizes the power within the framework of existing power plants. Therefore, less upfront costs and lucrative returns in short periods of time can be achieved. Estimated total EGSSS added steam is about 170t/h = 130MWt, which is recovered at 12% efficiency, and would become new and free 16 MWe in a couple of months without needing for additional drilling.

REFERENCES

Kizito O., 2010: Evaluation of Silica Scaling Potential after Second Flashing to 140°C. Selected wells from Olkaria East and North East. *KenGen Internal report.*

Navas H.F., 2006: Conversion and Conservation of renewable energy.

APPENDIXES

Hot separated Brine Energy can have 2 paths for its energy recovery – total 328 or 130 MWh

Electric energy production, MWe	
Heat exchanger: for heat exchange to binary system	**Controlled Second Flashing**: for additional steam
ORC systems	**EGSSS added steam**
20 MWe	**16 MWe**
$75 – 80 million Implemented 3 - 4 years	$ 15 million Implemented in 12 months
$3.3 – 4.0 M / **MWe**	$0.94 M / **MWe**
Requirements Collect and process information and data that will determine the amount of available energy and conversion to new power from the separated brine. Select and rank various technology options for the binary or alternate power generation from separated brine energy. Carry out Topographical, geophysical and geotechnical investigations to determine the suitability of the site(s) for the proposed binary or alternate installations for brine power generation. Elaborate a conceptual design for the recommended option of the brine power showing the binary plant or added steam installations layout. Propose electric power transmission system to ensure that the planned brine power will be evacuated to load centers. Prepare financial and economic analysis to demonstrate the viability cost and benefit of the recommended option over the project life. Feasibility Study. Elaborate an environmental and social impact assessment (ESIA) scoping for the recommended option of the brine power plant / installations. (A stand alone ESIA scoping report shall be prepared) Provide an implementation schedule for the recommended option of the brine power plant / installations. Plant Project Technical and Financing.	Requirements Modify separated steam and brine lines to allow 2nd flash and mix steam.