Enhanced Geothermal Systems Towards Environmental Management in Kenya: Case Study at Olkaria Geothermal Project

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ABSTRACT

Given the strength of commodity prices in recent years, concerns over energy security and widening adoption of carbon emission pricing, renewables are well positioned to play growing role in global energy mix. Geothermal energy is on the face of it. By harnessing the heat of the earth, geothermal power plants tap into a virtually inexhaustible and continuous source of energy, using a small footprint facility to provide baseload electricity that is virtually CO2 and waste free. Geothermal projects today center on the exploitation of hydrothermal resources- reservoirs of naturally occurring water. This could change with Enhanced Geothermal System (EGS), a new form of geothermal exploitation being tested in areas that are not hydrothermal. This paper discusses the prospect of Enhanced (or Engineered) Geothermal System as a means to the baseload power generation. It also focuses on the technology behind creating engineered reservoirs; it reviews the environmental impacts as well as possible mitigation measures

1.0 Introduction

1.1 Geothermal Energy

Geothermal energy is the energy contained as heat in the earth's interior. The origin of this heat is linked with the internal structure of our planet and the physical processes occurring there. Despite the fact that this is present in huge, practically inexhaustible quantities in the Earth's crust, not to mention the deeper parts of our planet, it is unevenly distributed, seldom concentrated and often at depths too great to be exploited industrially.

The heat moves from the earth's interior towards the surface where it dissipates, although this heat is generally not noticed. We are aware of its existence because the temperature of rocks increases with depth, proving that a geothermal gradient exists[1]: this gradient averages 30^0c/km of depth.

There are however some areas of the Earth's crust which are accessible by drilling, and where the gradient is well above the average. This occurs when, not far from the surface (a few kilometers) there are magma bodies undergoing cooling, still in a fluid state or in the process of solidification, and releasing heat .In other areas where magmatic activity does not exist, the heat accumulation is due to particular geological conditions of the crust such that the geothermal gradient reaches anomalously high values.

The extraction and utilization of this large quantity of heat requires a carrier to transfer the heat towards accessible depth beneath the Earth's surface. Generally the heat is transferred from the depth to sub-surface regions firstly by conduction and then by convection with geothermal fluids acting as the carrier in this case. These fluids are essentially rain water and has penetrated into the Earth's crust from the recharge areas and has been heated on the contact with the hot rocks and has accumulated in the aquifers, occasionally at high pressures and temperatures (up to 300^0c). These aquifers (reservoirs)are the essential parts of the geothermal fluids. In most cases the reservoir is covered with impermeable rocks that prevent the hot fluid s from easily reaching the surface keep them under pressure. We can produce industrial superheated steam or steam mixed with water or hot water only, depending on thee hydrological situation and the temperature of the hot rocks present. Wells are drilled into the reservoir to extract the hot fluids and their use depends on the temperature and pressure of the fluids: generation of electricity (the most important of the so-called high temperature uses), or for space heating and industrial processes (low temperature uses)

Geothermal fields as opposed to hydrocarbon fields are generally systems with a continuous circulation of heat and fluid and where liquids enter the reservoir from the recharge zones and leaves through discharge areas (hot springs, wells).During industrial exploitation fluids are recharged to the reservoir by reinjection through wells the waste fluids from the utilization plants. This reinjection process may compensate at least the fluid extracted by production, and will to a certain limit prolong the commercial lifetime of the field. Geothermal energy is therefore to some extent a renewable energy resource, hot fluid production rate tend however to be much large than recharge rates.

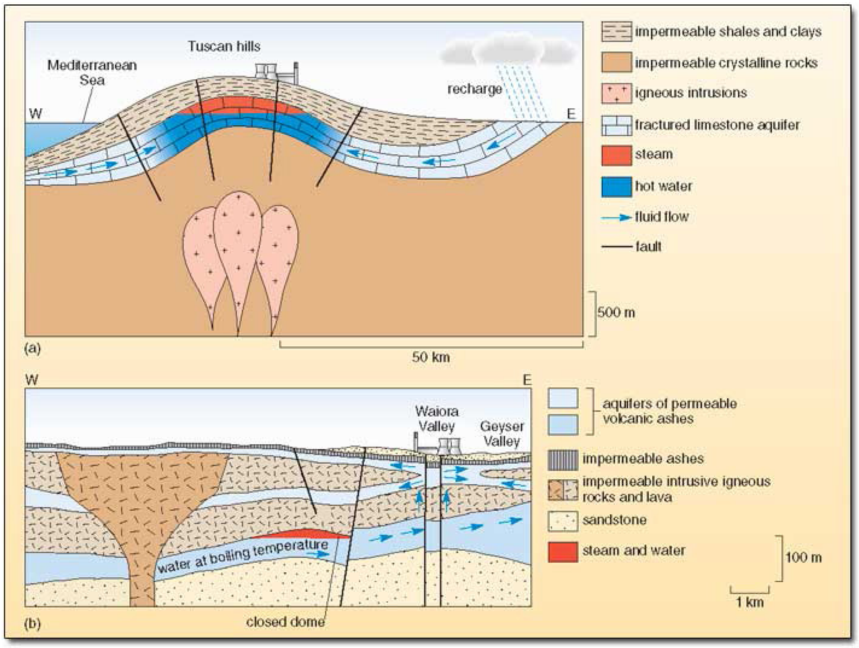

Figure 1. A geothermal steamfield elements: impermeable area reservoir and heat source.

1.2 Enhanced Geothermal Systems EGS[2]

Enhanced geothermal systems (EGS), also sometimes called engineered geothermal systems, offer great potential for dramatically expanding the use of geothermal energy. Present geothermal power generation comes from hydrothermal reservoirs, and is somewhat limited in geographic application to specific ideal places .EGS offers the chance to extend use of geothermal resources to larger areas of Kenya More than 100,000 MWe of economically viable capacity may be available in Africa, representing a 40-fold increase over present geothermal power generating capacity. This potential is about 10% of the overall Kenya's electric capacity today, and represents a domestic energy source that is clean, reliable, and proven.

1.2.1 The Concept

The EGS concept is to extract heat by creating a subsurface fracture system to which water can be added through injection wells. Creating an enhanced, or engineered, geothermal system requires improving the natural permeability of rock. Rocks are permeable due to minute fractures and pore spaces between mineral grains. Injected water is heated by contact with the rock and returns to the surface through production wells, as in naturally occurring hydrothermal systems. EGS are reservoirs created to improve the economics of resources without adequate water and/or permeability.

1.2.1 EGS Reservoir Development and Operation

Step 1: Identify a Site

In order to select an appropriate EGS site, it is crucial to understand the geologic characteristics of the area through field exploration. After surface exploration, an exploratory well is drilled to determine the permeability of the resource, and whether fluid is present. If the site possesses the necessary characteristics, an injection well is planned.

Step 2: Create a Reservoir

Drill an injection well into hot basement rock with limited fluid content and permeability. Inject water at sufficient pressure (or temperature differential) to propagate fractures by: opening existing fractures or creating new fractures. Continue pumping water to reopen old fractures and extend existing fractures throughout the developing reservoir.

Drill a production well into the fracture network intersecting as many of the flow points as possible.

The resulting circulation loop allows water to circulate through the enhanced reservoir along permeable pathways, picking up in situ heat. The hot water is then pumped to the surface through the production well.

Step 3: Operate the Power Plant and Maintain the Reservoir

At the surface, the water heats a working fluid that produces vapor to drive a turbine-generator.

Vapor travels through the turbine-generator to create electricity.

The original geothermal water is recycled into the reservoir through the injection well to complete the circulation loop.

EGS may be expanded by adding additional production and injection wells. This allows heat extraction from large volumes of rock and increases power generation capabilities.

1.2.2 Advantages of Enhanced Geothermal Systems

- Little to no gas emissions
- Provides baseload electricity
- Can be developed anywhere in the world

2.0 Geothermal Status in Kenya – Energy for the Future

The Geothermal status in Kenya presently stands at 209 MWe and this is mainly from the conventional geothermal methods. This is bound to increase sharply as she prepares to go EGS. the demand for renewable energy sources is also going to increase, but for the foreseeable future it will be limited, by industry's to provide it at competitive costs((*Spiegel & McArtur 2009*) Key factors that have led to the substantial growth in the renewable energy industry include: the high fossil-based energy costs related to increased demand and uncertainties in supply; economies of scale and falling capital equipment costs for alternative technologies, improving both yield and efficiency, and thereby improving competitiveness, legislative action by governments worldwide, greater public awareness of environmental concerns, particularly regarding greenhouse gases (GHG)[3] emissions associated with fossil fuels; the Kyoto protocol, through which certain countries have committed to reduce GHG emissions and which in turn motivates those governments to implement policies that decrease the use of fossil sourced energy and increase the use alternative technologies[4]

2.1 Policy Intervention

2.1.1 Kyoto Protocol[5]

The Kyoto protocol ratified in 2005, commits many developed countries to reduce their greenhouse gas emissions to specific targets. The protocol defined the clean development mechanism as a mechanism to help these industrialized countries to reduce the costs of meeting targets by buying certified emission reductions (CERs[6]), generated from different projects implemented in developing countries. The quantification of the CERs by different projectsi is made using a methodology that provides all steps to determine the emissions reductions in an accurate and conservative way.

2.1.2 Environmental Management and Coordination Act (EMCA 1999)

The Kenya government enacted EMCA to consolidate environmental status within a single frame work law to enhance environmental management in the country. The law provides for the environmental impact assessment and environmental audits for all projects likely to adverse negative impacts on the environment. National environment Management authority (NEMA) has further developed environmental impact assessment and audits regulations, 2003 to further the implementation of EIA/EA. The process ensures sustainable development while maintaining environmental integrity which directly addresses climate change challenges.

2.2.3 Kenya's Vision 2030

In preparation to curb climate change, the government came up with the carbon offset scheme to exploit opportunities within the Kyoto protocol on the establishment of voluntary carbon markets to promote conservation and compensation off for environmental services. To integrate planning approaches and improve overall governance of the environment by 2012, at least five, CDM projects per year in the next five years should be attracted (GoK 2007).

3.0 Technology used in Electricity Generation Enhanced Geothermal System EGS

There are three geothermal power plant technologies being used to convert hydrothermal fluids to electricity. The conversion technologies are dry steam, flash, and binary cycle. The type of conversion used depends on the state of the fluid (whether steam or water) and its temperature. Dry steam power plants systems were the first type of geothermal power generation plants built. They use the steam from the geothermal reservoir as it comes from wells, and route it directly through turbine/generator units to produce electricity. Flash steam plants are the most common type of geothermal power generation plants in operation today. They use water at temperatures greater than 360°F (182°C) that is pumped under high pressure to the generation equipment at the surface. Binary cycle geothermal power generation plants differ from Dry Steam and Flash Steam systems in that the water or steam from the geothermal reservoir never comes in contact with the turbine/generator units.

3.1 Dry Steam Power Plants

Steam plants use hydrothermal fluids that are primarily steam. The steam goes directly to a turbine, which drives a generator that produces electricity. The steam eliminates the need to burn fossil fuels to run the turbine. (Also eliminating the need to transport and store fuels!) This is the oldest type of geothermal power plant. It was first used at *Lardarello in Italy in 1904*, and is still very effective. These plants emit only excess steam and very minor amounts of gases.

3.2 Flash Steam Power Plants

Hydrothermal fluids above 360°F (182°C) can be used in flash plants to make electricity. Fluid is sprayed into a tank held at a much lower pressure than the fluid, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in a second tank to extract even more energy.

3.3 Binary[7]-Cycle Power Plants – at Olkaria

This is the mostly used power plant at Olkaria geothermal field. This field contains moderate-temperature water (below 400°F). Energy is extracted from these fluids in binary-cycle power plants. Hot geothermal fluid and a secondary (hence, "binary") fluid with a much lower boiling point than water pass through a heat exchanger. Heat from the geothermal fluid causes the secondary fluid to flash to vapor, which then drives the turbines. Because this is a closed-loop system, virtually nothing is emitted to the atmosphere. Moderate-temperature water is by far the more common geothermal resource, and most geothermal power plants in the future will be binary-cycle plants.

4.0 Environmental Management using Enhanced Geothermal Systems

4.1 Thermal Effluents

Waste heat is contained in the wastewaters and in the steam. The contained in the steam is principle heat used to generate electricity. Olkaria I plant,(EGS –binary) uses a cooling tower to vent out the heat to the atmosphere contained in the condenser outflow and the main impact resulting from this is on the local climate.Localised slight heating of the atmosphere an increased incidence of humidity lead to fogging, a common feature at Olkaria I power station area from June to August. The foggy conditions occur during the early hours of the morning and clears by 6.00 a.m. The waste water when disposed of on the surface like during well testing can have effects on the surrounding vegetation by scorching the plants dry. Carry over from under discharge have effects on local vegetation with shrubs and trees being scalded by escaping steam, this was evident when well OW[8]-714 under test (Were 1997).This effect is not permanent as the vegetation heals after the rains. To mitigate this impact at the Olkaria of the hot wastewater on vegetation deep reinection has been put, (EGS system), to serve as the solution/Like wastewater from OW -27 ,OW-31 andOW-33 (OW- olkaria well)are reinjected to well OW-03. Most of the geothermal wastewater is disposed off by deep reinjection.

4.2 Solid Wastes

Geothermal development produces significant amounts of solid waste, therefore suitable disposal methods need to be found. Because of the heavy metals particularly Arsenic, which are contained in the geothermal waters, these solid wastes are often classified as hazardous waste. During drilling, wastes are produced in the form of drilling muds, petroleum products from lubricants, fuels and cement wastes. Drilling muds are either lost through circulation in the well or end up in the drilling sumps as solid wastes for disposal. Since a lot of fuel as lubricants is used when drilling a single well,(apprix 300 000 liters of diesel) storage and transport of these products should follow sound environmental practice. During the operation of the power plant, as for Olkaria I plant, there is provision for safe storage of lubricants, and fuels. The principal solid wastes are cooling water sludge's which may contain Mercury. The waste brine from the power station that contains traces of solid wastes (heavy metal0 is safely disposed to the infiltration pond avoiding any spills, but the plan is to reinject[9] all these wastewater into one of the wells.

4.3 Chemical Discharge

Chemicals are discharged to the atmosphere via steam and into the ground water systems via liquid portion. Hydrogen sulphide gas emission is the major that causes the greatest concern due to its unpleasant smell and toxicity at moderate concentrations. At Olkaria geothermal power plant, measurements done in November-December 1991 recorded maximum 1 minute concentration of 1.25 ppm,(Sinclair Knight &and Partners, 1994) measurements in steam plume from OW (Olkaria Well) OW-709 Recorded measurements of around 0.15 ppm. Hydrogen Sulphide gas is measured a Olkaria by using a Sambre PM 200 series of personal gas monitors, which is designed to continuously monitor one gas. Monitoring is done three times a week for most locations around the power station and at least one in a week for those site further away. There are a total of ten main monitoring sites for H_2S (Table 1).These are distributed to cover residential areas (the side and the lakeview estate), occupational work place areas (power station, seal pit 1 & 2) workshop, stores administration block (Adm), areas of predominant wind direction(OW 10) and entry points to Olkaria (KWS Olkaria gate and gate near well 22).

The occupational exposure limit (O.E.L) of H2S in workplaces is 10 ppm for an averaged 8 –hour day. It is important to note that H2S at Olkaria are far below exposure limit, maximum figure recorded was at the power station 4.40 ppm (Table 1).

Table 1. H_2S Concentrations at Various Locations around Olkaria I Power Plant (Environmental BOC[10] report 1999).

W/S	P/S	Adm	SP 1	SP 2	W-10	W-22	KWS	LV
0.02	0.5	0.05	0.16	0.2	0.09	0.06	0.02	0
0.8	4.4	1.3	2.8	3.4	1.3	1	0.2	0.1
0	0	0	0	0	0	0	0	0
0	0.2	0	0	0	0W-22	0	0	0
Work-shop store	Power station	Aminis-tration	Seal pit	-	Well site	-	Kenya Wild service	Lake View estate

Carbon dioxide, which is usually the major constituent of geothermal gas, methane have been causing concern because of their role as greenhouse gases. However the carbon dioxide emission from the plants is small compared to fossil fuel Plant (Table 2.) and therefore any energy production fossil fuels that can be replaced by geothermal energy can be desirable. Carbon dioixide and Methane from geothermal is negligible source. Minor gases that cause concern.i.e Hg, NH3, and boron have not been found in dangerous concentrations in most of the geothermal plants in the world. At Olkaria these gases are not monitored in the emissions but are analyzed in geothermal wastewaters.Seperators are often inefficient and large quantities of water may be ejected from them over large areas as spray containing substances as boron that are harmful to plant life at high concentrations and Arsenic. Also high concentrations of silica are deposited on the ground. The main potential pollutants in the liquid effluents and which are monitored on quarterly basis at Olkaria include ,Arsenic Mercury, Lithium, Zinc, Cadmium, Lead, Table 3.The concentrations levels at Olkaria have been found to be below the optimum limits, above which these environmental components are considered contaminate or polluted. Surface disposal of such waters may be quite hazardous and can cause damage to flora and fauna as substances as Hg and As have been known to accumulate in plants and animals. This will not be desirable considering our developments are taking place in Hell's Gate National Park. Most of the effective method of solving the pollution by geothermal wastewaters (liquid effluent) is the reinjection of the spent fluids.

Table 2. Emissions of Carbon Dioxide and Suphur from Some Types of Power Plant (Armannsson, 1998).

Plant Type	Specific	C02 g/ kWh	S g KWh
Fossil Fuel	Coal	1000	11
	Oil	850	11
	Gas	550	0.005
Geothermal	Steam	960	6
	HDR	0	0
Solar	SEGS	140	0
	battery	0	0
Nuclear		< 1	0
Hydropower		0	0

Table. 3 Some Chemical Contaminants Monitored at Olkaria.

	Li	Cu	Zn	As	Cd	Ba	Hg	Pb	B
Sludge	-	1.6	0.47	0.017-	<1	0.167	0.001	0.6	-
Soil	0.4	1.63	13.5	-	0.123	5.1	-	3.05	-
Vegetation	0.7	0.54	10.3	-	0.03	1.2	-	1.25	-
wastewater	1.28	<Di	<Di	-	<Di	<dI	-	0.1	5.1
Lake water	<dI	<Di	0.02	0.001	0.001	0.001	0.001	00	0.11

5. Conclusion

Enhanced Geothermal energy is a clean energy source. The possible environmental impacts from its exploration include surface disturbance, physical effects due to heat effects and emission of chemicals. All these impacts can be eliminated through EGS. Olkaria geothermal project has not degraded the quality of the environment of the Hell's Gate National Park.

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[1] The heat moves upwards through rock faults; an indicator of geothermal resource.

[2] EGS Stands for enhanced geothermal systems.

[3] GHG Stands for greenhouse gases.

[4] Alternative technologies include; all green methods as geothermal hydro and EGS.

[5] Kyoto protocol-stipulates that all industrialized countries should reduce emissions up 2 % by 2012. Carbon trade is encouraged by the protocol (*administrative*).

[6] Binary means the substances have two ways of flow, a second liquid with lower temperature is involved, it's a modern technique.

[7] OW – Olkaria Well.

[8] Re-injection is a technique of waste disposal without harming the environment.

[9] BOC-Bank of china's report about the level of carbon dioxide at Olkaria1 power plant being small.