Water Dependency of Geothermal Power Generation Systems

(Esther Sironka.)

Kenya Electricity Generating Company (KenGen)

P. O. Box 785-20117

KENYA

esironka@kengen.co.ke

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ABSTRACT

Water and energy systems are interdependent and constitute the foundation for modern infrastructures around the World. In Kenya energy production and power generation systems are major users of freshwater resources besides agriculture.

This paper shows dependency of geothermal power generation systems on water availability and recommendations on ways of reducing water drawn from lakes and rivers by recycling, and reduction of wastage. The data for this study is extracted from publically available previous documentation and experiments done on sites. In estimating water use, water loss (e.g. evaporation losses) is considered water consumed. Water is not considered consumed if the withdrawn water is returned to the source and can be used again for other purposes such as recreation, fisheries and water supplies.

The water use processes for geothermal power generation technologies are not well documented in the literature. Thus findings of this report are based on approximate values. Adverse impacts of geothermal power generation systems on environment such as water and air contamination are not considered in this report.

The paper will report on quantity of water used on power generation, all water wastage observed and possible ways of recycling used water other than the already employed methods. The paper will also serve as a reference for future design of water distribution pipeline in geothermal power production field.

This paper will report on a case study in KenGen Olkaria geothermal field in Naivasha Kenya.

1. INTRODUCTION

Generating electricity from geothermal resources uses more water than any other form of electricity generation. But development of new cooling technologies and advanced energy-conversion techniques could reduce the stress on water resources.

Geothermal electricity generation uses two types of water – the water that is underground and used to extract the Earth's heat (geothermal fluid) and freshwater for drilling and cooling.

My research tracks the requirements for freshwater and geothermal fluid, and estimates withdrawal and consumption volumes for each of these two categories. Water withdrawal is the removal from a surface water body or aquifer. The water withdrawn is used both consumptively and non-consumptively. Water consumed is not immediately available for use by humans and the ecosystem in the watershed from which water is originally withdrawn .Water used non-consumptively is released back to the environment with or without change in quality, usually in the form of cooling tower blow down and is available for alternative uses in the same watershed.

Geothermal fluid is naturally occurring subsurface water that is withdrawn for heat mining. Depending upon local geological conditions, such fluids may have high concentrations of salts—chlorides, sulfates and bicarbonates; and dissolved gases like ammonia hydrogen sulphide and methane. The volume of fluids withdrawn per unit of electricity generated primarily depends upon the fluid temperature, the power-generating technology and efficiency of the power plant technology.

To the extent possible, geothermal fluids are collected and re-injected, but losses through several parts of the power generation cycle are inevitable. In flash power plants, for example, some or all of the geothermal fluid flashes to steam as it ascends from depth and enters the turbine. In the generation process, some of the fluid in the vapor state condenses to form high quality water with very low mineral content, which can then be used for cooling purposes. Evaporation of this water for cooling purposes is counted as geothermal fluid consumed. It is not considered freshwater consumption because it is not sourced from a body of freshwater. This escaped vapor also represents the amount of supplemental degraded water that needs to be injected into the geothermal resource to maintain pressure.

2.1 TYPES OF GEOTHERMAL POWER PLANTS

2.1.1 Conventional Hydrothermal Flash System

Hydrothermal fluids above 182°C (360°F) can be used in flash plants to make electricity . For the purposes of this assessment, temperatures between 175°C and 300°C were considered. The geo fluid is rapidly vaporized or “flashed,” either as it ascends from the well or at the plant, where the geo fluid flows into a tank held at a much lower pressure. The vapor drives a turbine, which then drives a generator. Any liquid that remains in the tank can be flashed again in a second system to generate more electricity. The vapors from these systems are typically released to the atmosphere while the condensate is re-injected to an underground reservoir.

2.1.2 Conventional Hydrothermal Binary System

Energy can be extracted in binary-cycle power plants from geothermal reservoirs with moderate temperatures between 74°C and 182°C . Geofluid temperatures between 150°C and 185°C were considered for this LCA. In binary-cycle plants, geothermal fluid is pumped from a well and flows through a heat exchanger to warm a secondary fluid, which is often referred to as the “working fluid.” The working fluid has a much lower boiling point than the geo fluid. The heat from the geo fluid causes the working fluid to flash to vapor, which then drives a turbine. 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; most geothermal power plants in the future will be binary-cycle plants.

2.1.3 Enhanced Geothermal System

EGS can expand the electricity-generating capacity of geothermal resources. By injecting water into the subsurface resource, existing fractures can be expanded or new fractures can be created to improve water circulation through the resource. These systems can be implemented in formations that are dryer and deeper than conventional geothermal resources. Temperatures considered for this LCA were between 175°C and 225°C. Because of the increased depths and temperatures, and decreased water availability, of the resources involved, environmental impacts from EGS can be different from conventional geothermal power plants

2.2 Water and Geothermal Electricity Generation

Geothermal electricity generation uses three types of water – the water that is underground and used to extract the Earth's heat (geothermal fluid); and freshwater for cooling.

Water is required for both traditional geothermal systems and EGS throughout the life cycle of a power plant. For traditional projects, the water available at the resource is typically used for energy generation during plant operations. Depending on the technology employed for electricity generation, production can lower the water table over time, affecting surrounding areas. In addition to being used for energy generation, water is also used for cooling the working fluid in the plant. Wet cooling towers are used when makeup water from nearby surface waters or other water supplies are available. Air cooling is an effective alternative when water supplies are limited.

Water is used for drilling wells; constructing wells, pipelines, and plant infrastructure; stimulating the injection wells in EGS; and operating the power plant. Although water extracted from the formation is re-injected after use, some water is lost to the formation. To maintain pressure and operation, water that is lost must be made up from alternative water sources.

2.2.1 Well Construction

The drilling phase of the geothermal power plant life cycle requires the use of drill rigs, fuel, and materials including the casing, cement, liners, mud constituents, and water. Water is used during the well construction stage as drilling fluids and for cementing the casing in place. The assumptions and methods used for construction as they pertain to water use are described in the following sections.

Well pad and infrastructure construction

A well pad is a compacted and leveled site where the drill rig, offices, and all drilling equipment are set.

The pad depends on the rig size. The pad is excavated, compacted and leveled to provide a good foundation for the drilling equipment.

Access roads to the well pad are constructed with gravel. These processes consume water during compaction and throughout the drilling period to curb dust pollution in the sites. The water used is not quantifiable and changes from site to site depending on the topography.

Drilling Fluids

During the drilling process, fluids or “muds” are used to lubricate and cool the drill bit and to convey drill cuttings from the bottom of the hole to the surface. To accomplish these tasks, drilling muds contain chemicals and constituents to control factors such as density and viscosity and to reduce fluid loss to the formation. Operators formulate muds on site and alter the recipe according to the physical conditions and chemical properties of the site and as conditions change during drilling. Muds are screened to remove cuttings brought to the surface, and are periodically changed during drilling in response to changing conditions. The mud remaining in the circulation system after drilling may be disposed or regenerated for future use.

The total volume of drilling muds depends on the volume of the borehole and the physical and chemical properties of the formation. As a result, mud volumes vary, and predicting the volume for a typical drilling project can be challenging.

Well Casing and Cementing of Casing

The volume of cement needed for each well was determined by the total volume of the well and the volume of the casing and interior.

Water dependency on the cementing process is in the following processes;

Clearing the well to remove all drilling residue with approximately 4000litres of water

In the cement slurry mix design

SLURRY DETAILS:				
	Scavenge	Lead	Tail	
SLURRY DENSITY	10.00	14.20	14.20	lbs./Gal
YIELD	2,487.50	900.00	900.00	l/t
WATER DEMAND	1,990.00	580.00	580.00	l/t
WATER DEMAND RATIOS	0.80	0.64	0.64	l(w)/l(s)

Displace Cement Slurry with about 35,000litres of water

Flushing the annulus with 14,000 liters of water

Cleaning the cementing equipment with 1000 liters of water

2.2.2 Power plant Construction

Water volumes for plant construction are limited to on-site use for concrete mixing. A typical concrete recipe requires approximately 200 g/L of water: concrete.

2.2.3 Operations

The vast majority of water used during operations is used to generate electricity. This water is commonly referred to as the geo fluid. In binary systems, the geo fluid is re injected into the reservoir. In a flash system, geo fluid that is flashed to vapor is released to the atmosphere and the condensed geo fluid is returned to the reservoir. In addition to electricity generation, water is used to condense vapor for;

(1) Reinjection in the case of the geo fluid

(2) Reuse in the case of the working fluid in binary systems. Water is also used in normal operations to manage dissolved solids and minimize scaling. The total flow rate of geo fluid through the plant depends on the flow rate produced from each well and the total number of production wells.

2.2.4 Cooling Water

Water is primarily used in cooling to condense steam. Thermoelectric cooling water needs for geothermal power plants were reported at 2,000 gal/MWh for withdrawal and 1,400 gal/MWh for consumption.

Cooling water withdrawal and consumption estimates are not the same for flash and binary power plants because of differences in vapor temperature, total mass of vapor requiring condensing, and the condensation point for working fluids in binary plants

2.3 KENGEN OLKARIA GEOTHERMAL POWER PROJECT CASE STUDY

The Greater Olkaria Geothermal Area is located in the Rift Valley about 120km from Nairobi. The field occupies an area of about 204KM² and the area currently underutilization is about 24KM². The estimated resource size is about 80KM²

KenGen Olkaria I power station is the first geothermal power plant in Africa. It has a capacity of 45MW .the turbines are direct condensing 4-stage running with an inlet steam pressure of 5 bars at temperatures of 150^0 c and steam consumption of 9.2 t/h/MW.

Olkaria II Power Station is Africa's largest Geothermal Power Station. It generates 70MW and is the second geothermal plant owned and operated by KenGen.

The second phase of Olkaria II was commissioned in 2010 injecting an extra 35 MW of power making a total of 150MW of power produced through geothermal means. This state-of-the-art plant is highly efficient in steam utilization. It works on single flash plant cycle with a steam consumption of 7.5t/h/MW. The turbines are single flow six stage condensing with direct contact spray jet condenser.

KenGen geothermal strategy is to develop 1,300MW by 2018. About 155MW has already been developed and the next phase of 280MW capacity will be commissioned by September 2014.

KenGen has been granted the license by the Government of Kenya to develop the Olkaria field which has an estimated potential of about 1200MW out of which, 155MW is developed and operated by KenGen and 52MW is developed and operated by Independent Power Producers (IPPs) leaving undeveloped resource potential of about 990MWe.

With funding from the Government of Kenya, KenGen commenced extensive drilling activities at the Olkaria field in 2006, and to date, a total of 63 wells with a steam capacity equivalent to 442.7MW have been drilled. About 320MW equivalent of steam would be dedicated to the development of the 280MW of the Olkaria I Unit 4&5 and the Olkaria IV Project currently under construction and scheduled for commissioning in the year 2014.

A detailed drilling program for the development of the next phase of 560MW has been commenced and will be executed continuously until the year 2018.

The main sources of drilling water have been Lake Naivasha supplemented by blow down from Olkaria 1 power station. With the increase in number of rigs, other sources of water need to be explored in order to meet the demand and avoid over abstraction of water from Lake Naivasha. Brine has been found to be the best immediate option.

Water Consumption

Around 90% of water abstracted from Lake Naivasha is used in drilling. The blow down from Olkaria1 power plant is being used in drilling instead of being re injected; as an alternative to fresh water in drilling. There are two booster pumps installed one with a head of about 200m and second one with a head of about100m. Olkaria II blow down is re injected.

Brine from separators at the wells is also re injected but there is the plan to use the brine for drilling by installing pumps at the reservoirs and pumping them to the drilling sites.

Well Construction

A sample of 5 wells at the geothermal field was reported to use the given quantities of fresh water and recycled water/brine.

well	Water used (m^3)			Drilling days	Depth (m)
	Fresh water	Brine (Recycled)	Total		
919D	56,000	-	56,000	61	3000
40A	30,000	43,000	73,000	99	3000
921A	16,000	61,500	77,500	51	3000

731c	71,200	-	71,200	62	3000
804B	19,950	98,018	117,968	75	3000

Average consumption of water for one rig is approximately 2000 l/min.

The factors affecting water used for drilling is the drilling period ,well temperatures, the higher the temperatures the more the cooling water is needed and the geology of the well site, some wells have more returns that need to be lifted to the surface.

Recommendations

1. Reuse water.

   Reusing water during construction can reduce the estimated volume of water for these activities. Drilling muds and hydraulic stimulation fluids are often reused when feasible. When multiple wells are drilled or stimulated on a site, temporarily storing fluids between activities could reduce overall water volumes.

2. Evaluate operational water use. For all geothermal systems evaluated, operational water consumption was the most significant contributor to water consumption over the life cycle. There is a lack of available data to identify where water consumption is occurring during operations, especially for air-cooled systems. Further evaluation could identify processes that are consuming water and possibly present opportunities for improving operational water use efficiency.

3. Consider non-freshwater makeup sources. If water availability is limited or there are several competing users for a single source, shifting water consumption to non-freshwater sources when feasible may be an effective solution to water consumption concerns. Alternative sources include oil and gas production water, carbon capture and storage production water, and saline groundwater.

4. Encourage use of binary systems. Binary systems were found to mitigate or minimize some of the major environmental and operational impacts resulting from the geo fluid composition. They eliminate the venting of NCG, reducing the carbon footprint and the need for hydrogen sulfide controls. They minimize or eliminate many of the key drivers of scale formation. Binary systems also enhance the sustainability of the reservoir by avoiding geo fluid evaporative cooling losses. Through these efforts, efficiency improvements can be made across the geothermal power plant life cycle to further reduce the impacts of geothermal power on freshwater resources.

DEADLINE

Full papers needs to be in our hands not later than July 30, 2014. Full papers should be sent to info@theargeo.org and technical@ theargeo.org.