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UTILIZATION OF BRINE FROM WELL 07 IN THE MENENGAI GEOTHERMAL FIELD FOR A GEOTHERMAL SPA

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ABSTRACT

In this report, a 1,000 m^2 geothermal spa alongside a 100 m^2 children's pool is designed to utilise the fluids from Menengai well 07. Cooling is done by using the heat in the geothermal fluid to vaporize a working fluid for a small binary power plant capable of generating 546 kW of electricity. The design characteristics, financial viability and the marketing elements of the spa are assessed. In Kenya, direct use of geothermal energy is gaining popularity and construction of geothermal spas is one way of making the resource, which is abundant along its rift, beneficial. A spa in the Menengai geothermal field would, therefore, raise the standards of tourism in the country and have a positive influence on the general health and wellbeing of the population due to its numerous benefits on the human body, mind and skin.

1. INTRODUCTION

Geothermal energy is heat generated and stored in the earth that can be recovered or exploited for use. According to Dickson and Fanelli (2004), temperature increases with depth at an estimated rate of 2.5-3°C/100m in most parts of the world, accessible by modern day drilling technologies. Exploration and development of geothermal resources has numerous benefits mostly governed by the location and temperature. Its major application is power generation since geothermal provides a stable base load for electricity generation, but there currently exist many examples of other non-power generation applications, particularly in the food and agriculture sectors (Nguyen et al., 2015). Based on temperature, geothermal resources are classified into three categories. Table 1 below (Gehringer and Loksha, 2012) outlines the classifications and their possible applications.

TABLE 1: Classification of geothermal resources (Gehringer and Loksha, 2012)

Type of resource	Temperature (°C)	Use/Technology
Low-enthalpy	<150	Power generation with binary power plant technology and direct uses
Medium-enthalpy	150-200	Power generation with binary power plants like the Organic Rankine Cycle (ORC) and the Kalina cycle
High-enthalpy	>200	Power generation with conventional steam, flash, double flash or dry steam technology

In conventional power generation, high temperature and pressure steam is used to drive turbines which in turn generate electricity. Electricity from geothermal resources is generated using high temperature steam or, in medium high temperatures, the binary power production technology. In most instances, the energy from geothermal resources used for power generation is only about 20% leaving about 80% which can be used for other applications conventionally known as direct uses.

About 10% of Kenya's gross domestic product (GDP) is through its manufacturing sector, which is the third largest energy end user of the country's economy and the largest consumer of electricity. The major source of energy for the industry is industrial diesel oil (IDO), heavy fuel oil (HFO) and wood pulp (Onuonga et al., 2011). These sources are not only expensive, but also pollute the environment by leaving a negative carbon footprint and firewood depletes forest cover. The use of heat from geothermal energy for industrial applications would, therefore, be beneficial in combating these negative effects. The heat energy left after power generation or from separation during generation can be combined with heat from hot geothermal fluids not suitable for power plants for use in these applications. Possible direct applications of geothermal energy would be drying, industrial process heat, as well as bathing and swimming. Bathing in geothermal water has been practised since ancient times across all continents and these facilities exist in large numbers today, drawing millions of the world population due to their association with treatment of diseases, fitness and a general feeling of relaxation.

Nakuru, the fourth largest urban centre in Kenya, is a county with about two million residents, numerous touristic attractions, has good weather all year round, is easily accessible from Nairobi, Kenya's capital, and is, therefore, strategically located for investors. It is the fastest growing town in East and Central Africa according to a recent study by the UN-Habitat (County Government of Nakuru, 2017). The county has a large untapped source of geothermal energy and is home to the Menengai crater, one of the biggest calderas in the world, and the Lake Nakuru National Park, home for flamingos, a pink beautiful wading bird. Inclusion of a geothermal spa in the wonders of this town would, therefore, make the area even more attractive for tourists, both for the local and international population.

This report explores the possibility of using the fluid (geothermal brine) in the design of a geothermal spa alongside a binary power plant. In the binary power plant, the brine will be pre-cooled before it is used for bathing in the spa.

2. GEOTHERMAL ENERGY IN KENYA

Kenya is estimated to have a population of more than 40 million inhabitants in an area of about 582,000 km^2 and an electricity consumption of about 7.86 billion TWh per annum (Worlddata, 2019). The country is endowed with abundant resources, amongst them geothermal energy which is estimated to have a capacity of more than 7,000 MWe (Simiyu, 2010), mostly along its rift valley. Figure 1 below shows the locations of the geothermal fields along the Kenyan rift. Among those geothermal fields where extensive exploration for geothermal resources has been carried out are Olkaria and Menengai. Exploration drilling in the Baringo-Silali geothermal block has also began. Electricity generation began in the 1980s in the Olkaria geothermal field with a current installed capacity of 774.4 MWe. Direct uses of geothermal energy have also been on the rise, though slowly. Some of these include:

i. Heating of a greenhouse at Oserian in Naivasha, where rose flower is grown, using fresh water heated by brine from a 1.28 MW well through a heat exchange process, Carbon dioxide (CO_2) enrichment and soil fumigation. This lowers the operational cost and increases productivity of the cut flower for export (Lagat, 2010).
ii. Drying of crops in a dryer that utilises natural steam from fumaroles at Eburru geothermal field.
iii. Domestic water harvesting from fumaroles at Suswa and Eburru.
iv. Bathing at the Lake Bogoria geothermal spa and in the recently constructed geothermal spa in Olkaria.

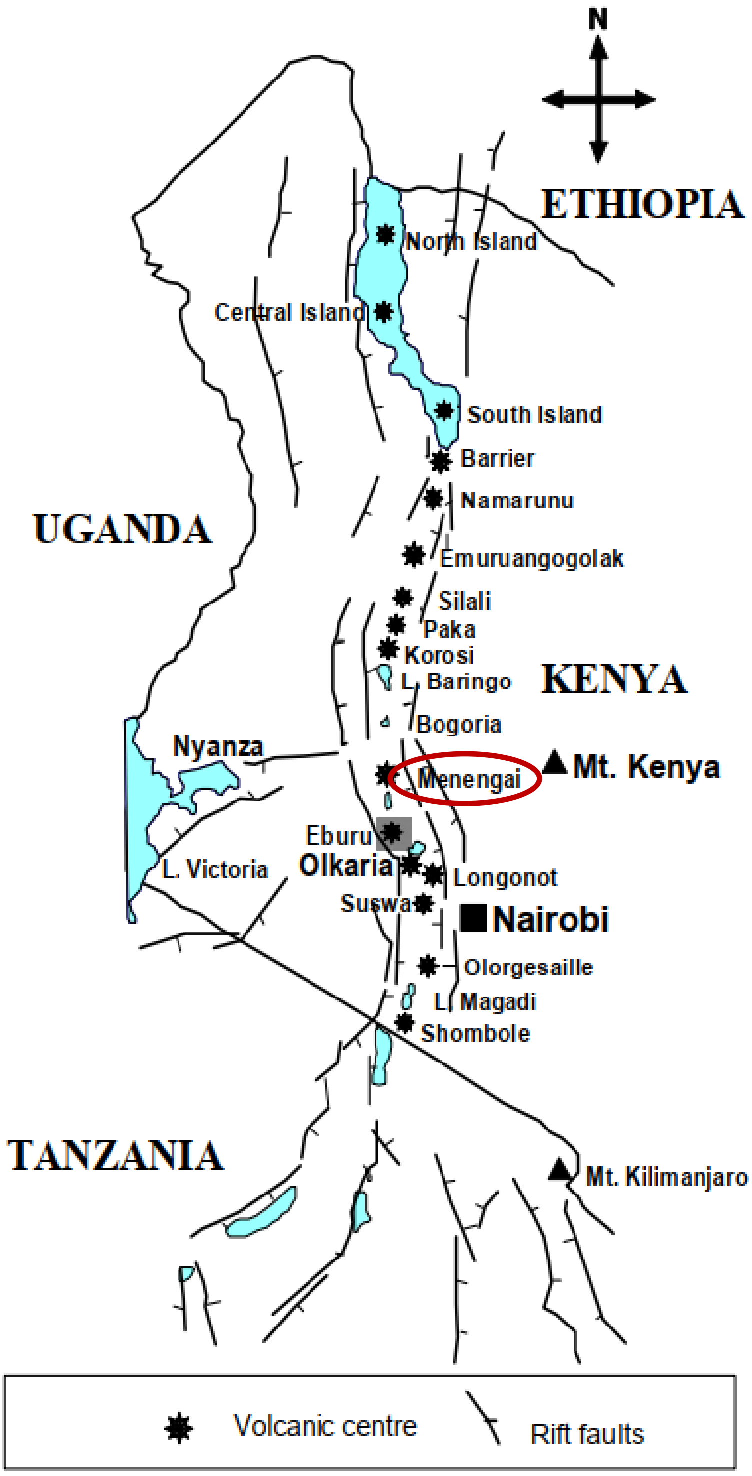

FIGURE 1: Kenya's geothermal rift (Muchemi, 2010)

The Geothermal Development Company (GDC) also constructed a direct use demonstration centre in 2015 in the Menengai geothermal field to display the suitability of using geothermal energy directly in milk pasteurization, fish and greenhouse farming and in a laundering and for drying garments.

2.1 The Menengai geothermal field

Menengai is in the Nakuru county on the floor of the Great Rift Valley in Kenya (Figure 1), approximately thirty kilometres North of Nakuru town and approximately 185 kilometres Northwest of Kenya's capital city, Nairobi. The field comprises of the Menengai Caldera, the Ol 'Rongai volcanic area and parts of the Solai Graben in the North East (Mibei et. al., 2016). It is one of the largest calderas in the world and boasts of rich histories, spectacular views of numerous flowering plants and grasses, animals and birds like the verreaux eagle, the Abyssinian ground hornbill and the African marsh harrier (Siyabona Africa, 2017). It is also a common place for outdoor activities such as hiking and picnics. The field has been categorized as a high temperature geothermal field by scientific studies and has an estimated geothermal potential of about 1,600 MWe (GDC, 2017). Exploratory drilling began inside the caldera region in 2011 to verify the resource. The Geothermal Development Company (GDC) has drilled more than thirty deep wells with the aim of retrieving high-pressure geothermal steam for electricity generation, starting with three 35 MW units. Steam is currently estimated to have a potential capacity of 160 MW (GDC, 2017). Among these wells are a few whose temperature and pressure are lower than the required minimums for the power plants. These wells are good candidates for direct applications of geothermal energy.

3. THEORY OF HEATED SWIMMING POOLS AND GEOTHERMAL SPAS

3.1 Background

The use of geothermal energy in balneotherapy and leisure has been among the main geothermal direct use applications since ancient times. Similarly, low and medium to high temperature geothermal resources have also been put into use by generating electricity through the binary method, utilising heat that would otherwise go to waste if only the flash power generation method was considered.

A swimming pool is a structure on or above the ground capable of holding water that will then be used for various activities like swimming, leisure and exercise or for recreational activities. Some types of pools have also been used for hydrotherapy. Swimming pools can be heated or unheated.

Geothermal spas on the other hand, utilize natural fluids from the earth. Therapeutic effects from thermal mineral water baths and spa therapy have been known worldwide for centuries. Balneological therapy emerged in the 1800s first in Europe then in the United States of America (Huang et al., 2018) and spas have since quickly gained popularity due to their unique elements which differentiate them from ordinary swimming pools. For instance, for thousands of years they are associated with health benefits and have been used both for treatment and for preventive therapy. The word spa is an abbreviation of the Latin expression "Salud Per Aqua" meaning "health through water" (Lund, 1999). In modern times, the term spa has been used to identify pools or bathing facilities that are primarily used for health and relaxation. Spas are naturally supplied with warm ground water or brine without addition of any chemicals, maintained at comfortable bathing temperature. The natural waters mostly contain minerals that are beneficial for health reasons (GeothermEx, 2000). Some of these benefits are believed to be detoxification, improved blood circulation and a general feeling of wellbeing and relaxation.

In Iceland, geothermal springs were used by the first settlers for bathing, laundering and cooking. Since the last century, heated outdoor swimming pools have also gained popularity and are today a part of life for most Icelanders. Other health uses for geothermal fluids in Iceland are the Blue Lagoon which is famous for helping curing psoriasis and other skin infections (Sigurgeirsson and Ólafsson, 2003), the Mývatn Nature Baths, and the health facility in Hveragerdi offering water and geothermal clay treatments. The hot waters could be from natural springs or from geothermal wells. The Dead Sea in Israel is also famous for its balneological therapy properties because its mud and water are extremely high in salinity, contain algae, sulphides, microorganisms and other bioactive materials beneficial to the human skin. Its bathers seek for the sulphur and mineral-rich baths which are believed to improve conditions like the plaque-type psoriasis and atopic dermatitis. The La Roche Posay Thermal Centre in France is also used to facilitate dermatologic thermal treatment (Huang et al., 2018).

The design of a heated swimming pool differs from that of a geothermal spa in that swimming pools commonly utilize fresh water which is treated, mostly by adding chlorine or bromine, while spas require minimal treatment of the bathing fluid as long as the fluid can be replaced fast enough using non-contaminated brine. Table 2 below is a summary of some of the differences between a heated swimming pool and a geothermal spa.

In order for a spa to be a successful venture, good hygiene, good service to the customer, and unique attractions and scenery must be maintained (Lund, 1999).

3.2 Swimming pools and geothermal spas in Kenya

Unlike in Iceland where people have been bathing for centuries, Kenyans are generally not accustomed to swimming and only a small part of the population does it for leisure. As a result, most swimming pools belong to the hotel industry and are usually not heated. Heating swimming pools and constructing spas in Kenya would, therefore, bring added value and attract more customers. There are two geothermal

TABLE 2: Differences between swimming pools and spas

Item	Heated swimming pool	Geothermal spa
Experience	No health benefits on the skin are expected after bathing	Health benefits for people with skin conditions
Safety	Easier to maintain safety standards due to ease of controls	More difficult to maintain the safety standards
Initial cost	Higher due to inclusion of controls; coagulant, chlorination and temperature regulation	Lower since no addition of chemicals like chlorination is done
Operational cost	Lower since most of the controls are automated	Higher due to little automation. There are possibilities of corrosion due to the chemical composition of the fluid and scaling due to cooling of brine in pipes and valves.
Technology required	Advanced technology due to controls and temperature regulation	Less technology needs due to less controls

spas in Kenya; the Lake Bogoria Geothermal Spa (Figure 2) operated by a hotel, utilizing warm water from a natural spring near the hotel, and the recently constructed geothermal spa (Figure 3) in the Olkaria geothermal field operated by the Kenya Electricity Generating Company (KenGen) which utilizes brine tapped from the main reinjection line to wells OW-R2 and OW-708 (Mangi, 2014). In other geothermal fields, for instance in Kapedo in the Silali geothermal field, the local population also use the warm springs to bath and launder their clothes, although only on a small scale.

FIGURE 2: Lake Bogoria geothermal spa (Lagat, 2008)

FIGURE 3: Olkaria geothermal spa (Mangi, 2015)

A spa in the Menengai geothermal field would come as a big boost to the utilization of geothermal resources in Kenya and to the tourism industry but must be of high international quality standard in order to draw the local population and attract international tourists visiting Kenya. Since most Kenyan families love entertaining their children, the facility must also provide extra amenities for children entertainment.

3.3 Menengai well 07

FIGURE 4: A section of the Menengai crater featuring Lion Hill viewpoint (Wetang'ula, 2015)

This was the seventh well in the Menengai geothermal field completed in June 2012 and is characterized by a spectacular view and a beautiful indigenous forest (Figure 4). Its location has an elevation of 1942 m above sea level on 1704887.000 Eastings and 9977450.999 Northings. The well has a clear depth of 2,118 meters and produces a liquid dominated mixture of geothermal steam and water. Table 3 below outlines some of the physical and chemical characteristics of Menengai well 07.

TABLE 3: Physical and chemical characteristics of Menengai well 07 geothermal fluid (GDC, internal communications)

Parameter	Unit	Value
Downhole Temperature	°C	117.46
Wellhead Temperature	°C	100
Well head Pressure	bar-g	2.84
Discharge Enthalpy	kJ/Kg	557
pH	-	9.2
CO_2	mg/kg	8,088
H_2S	mg/kg	0.39
Boron	mg/kg	0.95
SiO_2	mg/kg	324.15
Na	mg/kg	1,176.75
K	mg/kg	115.37
Ca	mg/kg	0.06
F	mg/kg	108.15
Cl	mg/kg	681.18
Sulphates (SO_4)	mg/kg	469.46
Ammonia (NH_4)	mg/kg	14.51
TDS	mg/kg	7351.88
N_2	mmole/kg	59.74
O_2	mmole/kg	3.67
Conductivity	µΩ/cm	15290
Total Mass Flow Rate (t/hr)	t/hr	110.00
Water Flow Rate (t/hr)	t/hr	100.18

3.3.1 Chemistry of the well in comparison with other geothermal waters

Waters for use in balneotherapy are different in hydro geologic origin, temperature and chemical composition. While there may be no standard protocols for treatment obtained from bathing in thermal waters, different chemicals could have different effects on the human skin and body. There are different classifications of thermal spring water, depending on their chemical compositions (bicarbonate, sulphate, sulphide, chloride and trace metal mineralization or by temperature; cold (<20°C), hypothermal (20-30°C), thermal (30-40°C) or hyperthermal (>40°C) (Huang et al., 2018).

Thermal water with curative properties is termed as mineral water (Shankin-Uz-Zaman, 2013) while the chemical composition of the water determines its curative and therapeutic effects. Mineral waters have also been classified based on the total minerals, ion and gas composition, temperature, its active therapeutic components, acidity and alkalinity. Thermal water is considered curative if it possesses the properties outlined in Table 4 according to the International Association of Spas, Health Resort and Balneology, the International Society of Medical Hydrology, the International de Technique Hydrothermal (SITH) and the German Health Resorts Association (Shakhin-Uz-Zaman, 2013).

Thermal water containing sodium, carbon, magnesium, chlorine and sulphates is considered to have therapeutic properties. Trace elements like aluminium, arsenic, copper, iron, cadmium, lead, strontium, manganese and zinc are also considered to have medicinal properties (Harahsheh, 2002). Table 5 shows an analysis of water in a warm spring in Georgia whose temperature was reported to be 31°C and is famous for bathing (Lund, 1996), while Table 6 shows the European Union (2009) and US Spa Standards for mineral water for various applications (European Union 2009, Shakhin-Uz-Zaman, 2013).

TABLE 4: Curative properties in thermal fluids (Shankin-Uz-Zaman, 2013)

Element	Value	Units
TDS	>1,500	mg/l
Fe	20	mg/l
I	1	mg/l
H_2S	1	mg/l
F	1	mg/l
Temperature	>27	°C

According to the properties of Menengai well 07 outlined in Table 3, a preliminary check of the chemical characteristics indicates that the geothermal fluid from the well is suitable for bathing and consist minerals beneficial to the human body and skin especially when maintained at temperatures above 27°C. However, a detailed chemical test of the brine will need to be done to confirm the safety and suitability of the fluid before bathing.

TABLE 5: Water characteristics of Warm Springs, Georgia (from untitled paper prepared by The Warm Springs Institute)

Mineral	mg/L	Proposed treatment
Bicarbonate (ion)	118	Diabetes, gout, rheumatism, dyspepsia
Silica	24	Cancer and sugar in the blood
Calcium	21	Diarrhoea, gall and kidney stones
Magnesium	12	Dyspepsia, constipation, haemorrhoids
Sulphate (ion)	7.6	Syphilis, scrofula, rheumatism
Potassium	3.6	Catarrhal jaundice
Sodium	1.9	Gall and kidney stones, gout
Chloride	1.8	Eczema, acne, stomach, rheumatism
Nitrate (ion)	0.13	-
Fluoride	0.10	Prevents tooth decay
Iron	0.01	Anaemia
Total hardness	102	

TABLE 6: EU (2009) and US Spa Standards

Parameter	Unit	EU (2009) and US spa standards
pH	-	7.2-7.6
Temperature	°C	29-35
EC	μΩ/cm	>2308
SiO_2	mg/l	>1500
HCO_3	mg/l	>600
H_2S	mg/l	>1
TDS	ppm	>1500
Na	Mg/kg	>200
Mg	Mg/kg	>50
SO_4	Mg/kg	>200
Cl	Mg/kg	>200
F	Mg/kg	>1
Al	mg/l	0.02
As	mg/l	6×10^{-6}
Ba	mg/l	0.08
K	mg/l	0-90
Ca	Mg/kg	>150
B	mg/l	0.08
Cd	mg/l	3×10^{-6}
Cr	mg/l	35×10^{-5}
Cu	mg/l	5×10^{-6}
Fe	mg/l	>1
Hg	mg/l	7×10^{-6}
Mn	mg/l	0.023
Pb	mg/l	<4
Sr	mg/l	5.3
Zn	mg/l	<5

4. DESIGN OF THE GEOTHERMAL SPA

The design of this spa will be adopted and modified from lessons learnt from two geothermal spas in Iceland (The Blue Lagoon and the Mývatn Nature Baths). Table 7 below shows the characteristics of the two geothermal spas (Hjálmarsson, 2014).

The Mývatn Nature Baths are served with 130°C hot brine from the National Power Company´s borehole in Bjarnarflag. The hot brine flashes into a big pot which serves as a cooling system and helps in getting rid of any present harmful geothermal gases. Cooling is achieved through loss of heat by latent heat of vaporisation in the pot and convection through heating of fresh water for use in the showers through a heat exchange process. Brine at a temperature of around 90°C is then mixed with a percentage of cold brine from the spa and the mixture then flows by gravity into the lagoon through five feeding points. The temperature in the lagoon is controlled using temperature sensors located in the feeding points to ensure that the temperature is maintained at 36-40°C.

TABLE 7: Characteristics of the Blue Lagoon and the Mývatn Nature Baths

	Blue Lagoon	**Mývatn Nature Baths (Jarðbödin)**
Location	Reykjanes Peninsula, SW-Iceland the Svartsengi high-temperature field	Námafjall, high-temperature field, NE-Iceland
Area	8,700 m^2	5,000 m^2
Volume of water in spa	9×10^6 L geothermal seawater	3.5×10^6 L geothermal water
Temperature	37-39°C	36-40°C
Average number of guests per year	More than 1,000,000	More than 400,000

The Blue Lagoon has an average depth of one meter. It gets its 160°C hot brine from the nearby Svartsengi geothermal power plant and is in the midst of craggy black lava, giving the spa a stunning scenery. The hot geothermal brine is fed into the lagoon at high pressure in mixing boxes which are equipped with temperature control sensors and allow mixing with cold brine in the lagoon. The lagoon receives a daily average of 3,000-4,000 guests with an average dwelling time of two hours. For safety reasons, bi-weekly samples of the brine in the lagoon are taken and subjected to tests to ensure a healthy bathing environment for the guests with a reference to the Blue Flag Standards (2014).

A comparison of the chemical constituents of the brine at the Blue Lagoon and Mývatn to Menengai well 07 is shown below (Table 8).

TABLE 8: Comparison of physical and chemical constituents of the Blue Lagoon, Mývatn Nature Baths and Menengai well 07 in mg/kg

Parameter	**Menengai well**	**The Blue Lagoon** (Sigurgeirsson and Ólafsson, 2003)	**The Mývatn Nature Baths** (Ármannsson et al., 1998)
pH	9.2	-	7.04
CO_2	-	16.5	30.1
H_2S	-	0.00	0.14
SiO_2	324.15	-	280.8
Na	1,176.75	9,280	142
Mg	-	1.41	0.29
Ca	0.06	1,450	2.02
K	115.37	1,560	20.1
SO_4	469.46	38.6	-
Cl	681.18	18,500	-
F	108.15	0.14	-

4.1 Scope of works

The spa will comprise of a large adult lagoon and a small children's pool alongside other accompanying facilities. The sidewalls will contain benches (sitting allowances) in about 30% of the area. A binary power plant will be installed and will generate electricity as well as cool the hot brine before it is used in the spa. The surroundings of the entire spa area will be made of lava rocks from the Menengai geothermal field. Brine will enter the spa in five locations through mixing chambers with thermostats for temperature control. A tank with a large surface area will be required for cooling the brine in case the power plant is not operational, is being maintained or any additional cooling is required.

A spa building will be constructed with shower areas and toilets for both genders. There will also be a reception area which will require at least one extra rest room for each gender. A beverage service area on one side of the spa where guests can be served with a drink while inside the spa will also be factored in. There will be a room where medical equipment is available with a medical staff positioned in it to attend to guests with medical needs. Provision must be made for a parking lot that will have outdoor lighting.

A pipeline will be put in place to transport the brine from its source (Menengai well 07) to the binary power plant, to the heat exchanger, to the spa and to the reinjection well after use. There will also be a pipeline for the fresh water. A heat exchanger which will use hot brine to heat the cold fresh water for the showers will be purchased and installed. The heated water will be stored in an insulated tank to ensure continuous availability and balanced pressure during use.

A sewerage system will also be provided for and will comprise of a concrete septic tank and a drain field capable of handling all the wastewater from the shower rooms and the service areas in the spa. Brine that has already been used in the spa flows to the reinjection well in Menengai.

4.2 Location of the proposed spa in Menengai

The spa will be located near Menengai well 07 where the brine will be sourced (Figure 5). However, provision will be made for a future connection for separated brine at the power plant before reinjection. The location is ideal since it is served by an all-weather road and is near a 3-phase electricity connection and a source of fresh water.

FIGURE 5: Proposed location for the spa near Menengai well 07

4.3 Type and size of the spa

It is necessary that the facility meets the standards for a geothermal spa. Minimum requirements are that geothermal spas offer benefits of health, beauty and body relaxation. In comparison to the Blue Lagoon and the Mývatn Nature Baths, the brine from Menengai meets the minimum requirements for bathing with health benefits because of its silica content. It is predictable that the spa water will be of blue colour typical of most geothermal spas.

4.3.1 Size of the spa

The following factors must be considered when assessing a suitable spa size:

i. Availability of brine for the spa
ii. The desired number of customers
iii. Energy balance of the fluids for the spa

The design of the spa will be based on the following assumptions:

1) Table 3 describes the parameters of the well
2) The chemical composition of the brine is beneficial for bathing
3) Two hundred guests will bathe in the spa every day for 360 days in the year, 50 of them international guests and 150 locals.
4) International guests will pay an entrance fee of USD 25 while local tourists will pay USD 5
5) Each guest will occupy an area 5 m^2 and the spa can accommodate 200 guests at a time
6) Each guest will take a shower before and after bathing in the spa
7) Each guest will use the rest rooms at least once during their stay at the spa

From the assumed number of guests and the area each guest occupies in the spa, a 1,000 m^2 spa is designed. Provision for an extra 100 m^2 will be made to allow room for children accompanying parents and guardians to also bathe in the spa. A temperature of 37°C is required in the main lagoon and the highest temperature for the steam room is 60°C. A binary cycle power plant is incorporated in the design to utilize the heat energy in the brine that would otherwise evaporate during cooling. This has the advantage that the produced power can be used for the facility's electricity needs. Provision have however to be made for further cooling of the brine after power generation which can also serve as alternative cooling in case the power plant is not running or is being maintained. Alternative cooling of the brine will be done using a big tank where brine will be flashed to allow the fluid to lose a considerable amount of heat through latent heat of vaporisation before it is mixed with colder brine in the lagoon in the mixing boxes. The boxes must be equipped with thermostats which will regulate the temperature in the spa by increasing or decreasing the flow rate of the hot brine into the spa.

4.3.2 Cooling of the brine – Binary power plant

A binary power plant is designed to utilize low-grade heat or otherwise low process heat that would not be used in the conventional power plant to produce electricity. For temperatures below 180°C, the binary power generation is considered more economical than the flash cycles. A suitable hydrocarbon, normally referred to as a working fluid, must be selected depending on its thermodynamic principles. The name binary is derived from the fact that there are two fluids, that is the geothermal fluid and the working or secondary fluid. Two types of binary power plants exist: The Organic Rankine Cycle (ORC) and the Kalina Cycle (Valdimarsson, 2011). Binary power plants use a thermodynamic principle like a conventional fossil or nuclear power plant since the working fluid is in a closed cycle. As a result, the fluid is completely isolated chemically and physically from the environment (DiPippo, 2012).

In a binary power plant, the hot geothermal fluid is directed to a heat exchanger where the working fluid of lower boiling point and high vapour pressure is vaporised. The vapour generated is used to drive a turbine and produce electricity. The thermodynamic properties of a working fluid like the critical temperature and pressure have a great influence on the performance of the system. However, other factors are also considered like cost, health, safety and environmental impacts of the fluid. Table 9 below shows selected working fluids and their characteristics in comparison to water.

TABLE 9: Environmental and health properties of selected working fluids (DiPippo, 2012)

Fluid	Formula	Toxicity	Flammability	ODP *	GWP **
R-12	CCl_2F_2	Non-toxic	Non-flammable	1.0	4,500
R-114	$C_2Cl_2F_4$	Non-toxic	Non-Ffammable	0.7	5,850
Propane	C_3H_8	Low	Very high	0	3
i-Butane	i-C_4H_{10}	Low	Very high	0	3
n-Butane	C_4H_{10}	Low	Very high	0	3
i-Pentane	i-C_5H_{12}	Low	Very high	0	3
n-Pentane	C_5H_{12}	Low	Very high	0	3
Ammonia	NH_3	Toxic	Lower flammability	0	0
Water	H_2O	Non-toxic	Non-flammable	0	-

*ODP = Ozone depletion potential; *GWP = Global warming potential

A basic binary power plant consists of the following equipment (Dippipo, 2012):

1) The brine supply system
2) Downhole pumps and motors
3) Heat exchangers consisting of a pre-heater and the evaporator
4) Turbine, generator and controls
5) Condenser, accumulator and storage system
6) Working fluid pump system
7) Heat rejection system
8) Backup system
9) Brine disposal system
10) Fire protection system (if the working fluid is flammable)

Design of the binary power plant:
The binary plant is designed using the following assumptions:

- Brine mass flow rate: 30 kg/s
- Wellhead pressure: 2.5 bar
- Ratio of steam to brine: 1:45
- Well enthalpy: 471.8 kJ/kg
- Geothermal water inlet temperature: 100°C
- Geothermal water outlet temperature: 60°C
- Cooling water mass flow: 90 kg/s
- Cooling water inlet temp: 17°C
- Working fluid: Iso-pentane
- Isentropic turbine efficiency: 85%
- Pump efficiency: 80%

Using the assumptions above, a binary power plant is designed using the Engineers Equation Solver (EES) (Figure 6). The power plant output would be 546 kW. Brine at 60°C will then flow into the lagoon for bathing at five feeding points equipped with temperature regulation thermostats. A small part of the brine would be used to heat up water for use in the showers through a heat exchange process.

A plate heat exchanger would be used because of its high efficiency in heat transfer during the heat exchange process. Hot brine would then be mixed with the brine already in the lagoon where rapid mixing will maintain the bathing temperature between 37 and 40°C.

In the model above, the working fluid (Iso-Pentane) enters the vaporiser at point 4 and is heated by hot brine in the heat exchanger. At point 1, the vaporised fluid moves and turns the turbine blades which in turn generate electricity. The vapour then exits the turbine at point 2 and enters the condenser and is condensed into a liquid. It exits the condenser at point 3 where a pump is used to raise its pressure to allow re-circulation through the cycle.

4.3.3 Energy balance of the fluids for the spa

Heat in a spa or a swimming pool is lost mainly through:

- Convection
- Evaporation

Other contributors of heat loss are:

- Radiation
- Conduction
- Rain

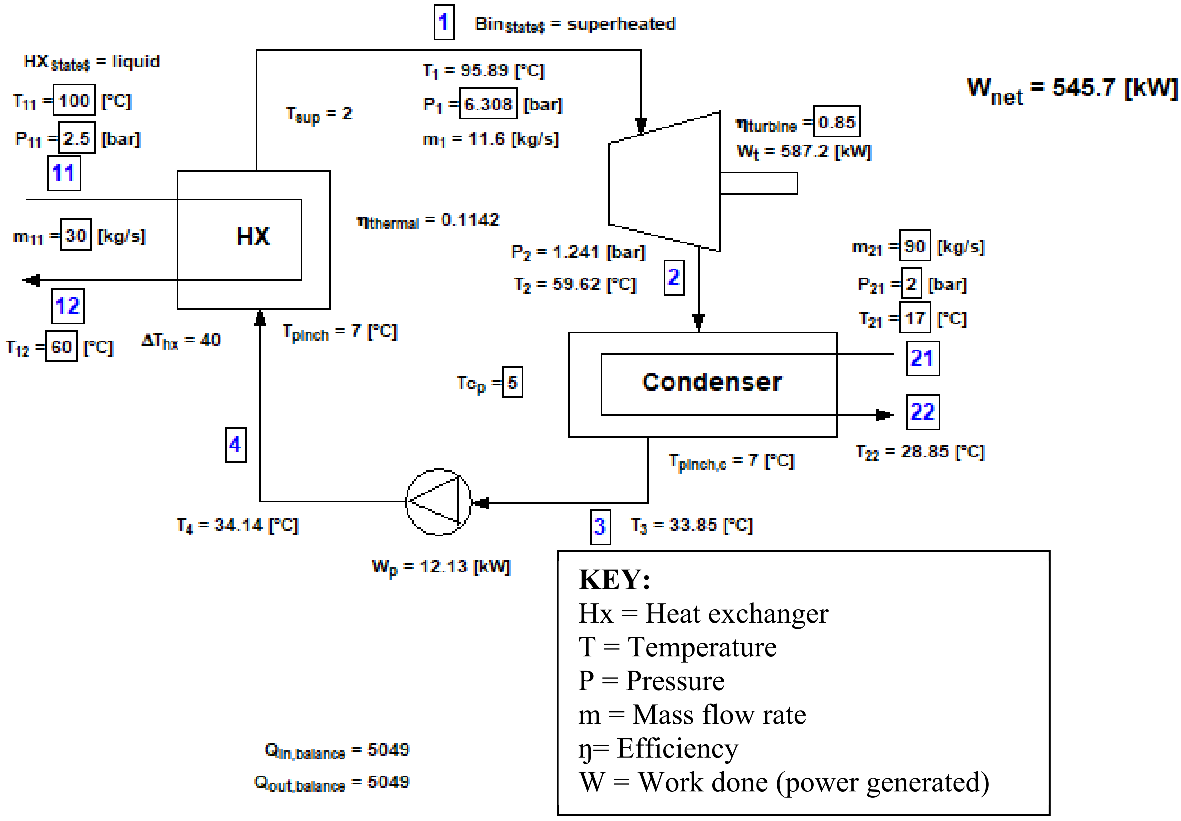

FIGURE 6: Model of binary power generation (created with EES)

Figure 7 indicates the various ways that heat is lost in a spa.

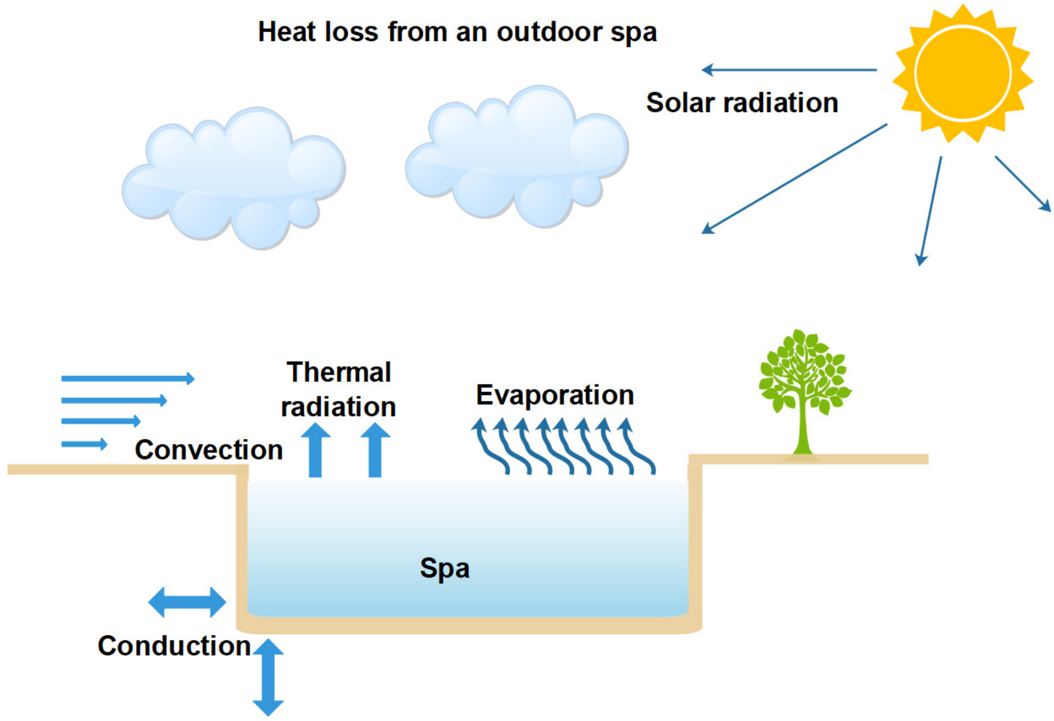

FIGURE 7: Heat loss in the spa

The heat losses are dependent on the prevailing weather conditions. Table 10 below shows the monthly average weather data which were collected and recorded hourly in Menengai in the year 2018.

TABLE 10: Average weather data for Menengai, 2018 (Internal Communication)

Month / Parameter	Wind speed (m/s)	Air temperature (°C)	RH (%)	Sunshine (W/m^2)	Rain (mm)	BP (mbar)
Jan	4.32	20.16	44.63	6.84	0.01	492.17
Feb	4.86	20.97	43.18	10.81	0.01	483.48
Mar	3.39	19.24	66.47	50.16	0.42	531.05
Apr	2.48	18.22	76.73	104.14	0.58	617.09
May	3.24	18.44	73.19	53.86	0.35	643.38
Jun	3.27	18.37	69.10	37.61	0.22	635.09
Jul	4.28	18.16	61.36	38.77	0.10	606.90
Aug	4.01	18.51	60.61	35.31	0.19	606.23
Sep	3.88	19.06	56.77	18.22	0.13	605.02
Oct	3.26	18.63	63.06	23.23	0.12	598.41
Nov	2.98	18.43	64.48	13.96	0.10	595.78
Dec	2.91	18.85	62.89	7.51	0.11	579.10

Figure 8 below is a graphical representation of the temperature variations in a typical week in Menengai.

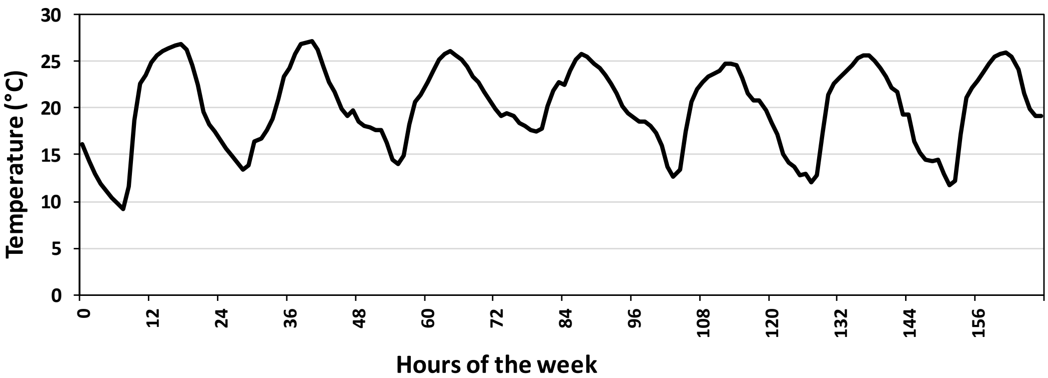

FIGURE 8: Daily temperature variation in a week

Assumed weather parameters for wind speed, air temperature, relative humidity and rainfall were used to calculate the heat losses for the spa which will influence the quantity of brine required to keep the temperature of the spa 37°C. The selected design parameters are shown in Table 11.

TABLE 11: Design parameters

Parameter	Units	Value
Wind speed at 2 m above ground	m/s	4.8
Air temperature	°C	17
Relative humidity	%	65
Air temperature when raining	°C	10
Average rainfall in 24 hours	mm	5
Inflow brine temperature	°C	60
Spa (bathing) temperature	°C	37

Heat loss by convection, Qc

Convection is the transfer of heat within a fluid by the displacement of one portion of the fluid by another. The flow of the heat depends on the properties of the fluid and the shape of the surface. It is, however, independent of the properties of the material of the surface (Rajput, 2007). Heat loss by convection is defined using Equation 1 below:

$$Q_C = h_c\,(T_w + T_a) \tag{1}$$

where Q_c = Heat loss by convection (W/m^2);

T_w = Water temperature (°C); and
T_a = Air temperature (°C).

$$h_c = K + 1.88V \tag{2}$$

$$K = 3.89 + 0.17\,(T_w - T_a)\ (W/m^{2/}°C) \tag{3}$$

where V = Wind speed measured 2 m above the ground (m/s).

Assuming an air temperature of 16°C and a spa temperature of 37°C, then the calculated value for heat loss by convection would be 326 W/m^2.

Heat loss by evaporation, Qe
Heat loss by evaporation is calculated in W/m^2 using Equation 4 below:

$$Q_e = (1.56K + 2.93V)(e_w - e_a) \tag{4}$$

where Q_e = Heat loss by evaporation (W/m^2);
e_w = Partial pressure of steam at the surface (mbar); and
e_a = Partial pressure of steam in air (mbar).

If the average humidity of the air is 60%, the partial pressure for the steam at 17°C is 12.6 mbar. Saturation pressure at a temperature of 37°C with a humidity of 100% is 62.6 mbar. The calculated value for the heat lost by evaporation is, therefore, 1,277 W/m^2.

Heat loss by radiation, Q_R
Transfer of heat by radiation occurs when energy is transferred across a system boundary by means of an electromagnetic mechanist solely controlled by temperature difference. Radiation does not require a medium unlike heat transfer by convection and conduction. Equation 5 below was used to calculate heat loss by radiation:

$$Q_e = 4.186\left((13.18 * 10^{-9} * \ T_a{}^4\ (0.46 - 0.06 * e_a{}^{0.5}\right) - G_0 * (1 - a)) * (1 - 0.012 * N^2) + 13.18 * 10^{-9}\ (T_w{}^4 + T_a{}^4) \tag{5}$$

where Q_R = Heat loss by radiation (W/m^2);
G_0 = Radiation of the sun in clear weather in (cal/s/m^2);
A = Natural reflection of water; and
N = Cloudiness factor ranging 0-8.

For maximum energy requirements in the design, a value of zero is assumed for both radiation of the sun and the cloudiness factor. The calculated heat loss by radiation is 216 W/m^2.

Heat loss by conduction, Q_L
Heat is transferred by conduction when substances are in physical contact with each other without appreciable displacement of molecules forming the substance or when heat is transferred from one part of the substance to another. In a spa, heat loss occurs due to the physical contact between the heated fluid and the walls and other substances. For this design, heat loss through the pool walls is estimated to be 0.5 W/m^2 and the heat loss at the bottom is assumed negligible. It is also assumed that the total surface area of the walls is one third of the surface area of the pool as shown in Equation 6 below:

$$Q_L = 0.5 * \frac{1}{3}\,(T_w - T_a) \tag{6}$$

where Q_L = Heat loss by conduction (W/m^2).

The calculated heat loss by conduction is 3 W/m^2.

Heat loss by rain, Q_P

Rain that falls into the pool needs to be heated up to the pool water temperature. The heat required for this can be calculated as shown in Equation 7 below:

$$Q_P = m_P * cp * (T_P - T_W) \tag{7}$$

where Q_P = Heat loss by rain (W/m²);
m_P = Rate of rainfall (kg/s);
c_p = Specific heat capacity of water (J/kg/°C); and
T_p = Rainwater temperature (°C).

The calculated heat loss by rain is 216 W/m².

Table 12 below is a summary of the calculated results for heat losses for the proposed 1,000 m² spa and 100 m² children's pool and the required average brine flow rate to maintain the spa at 37°C.

TABLE 12: Heat loss and brine flow rate

Item	Units	Value
Heat loss by convection	W/m²	326
Heat loss by evaporation	W/m²	1,277
Heat loss by radiation	W/m²	216
Heat loss by conduction	W/m²	3
Heat loss by rain	W/m²	216
Total heat loss	W/m²	2,038
Total thermal power required	MW_t	2.2
Brine flow rate required	kg/s	27

Heat loss by evaporation is the highest, its biggest influence being the wind speed. It is recommended that an anemometer is installed on site before the onset of construction to monitor the accuracy of the wind speed. A lower wind speed would lead to lower heat losses and vice versa which also influences the required quantities of brine for the spa. The size of the spa would, therefore, be altered depending on the amount of brine available for the spa. Figure 9 is a graphical representation of the different types of heat losses.

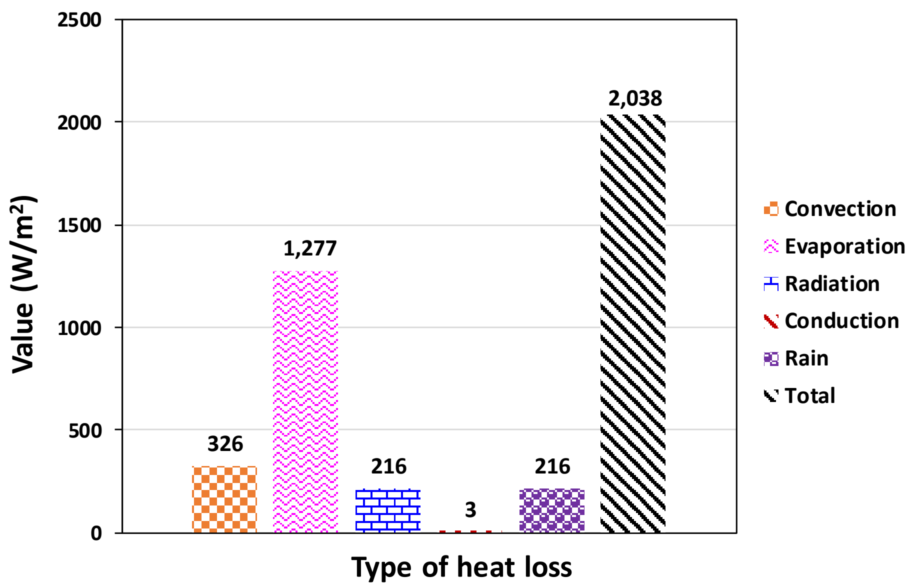

FIGURE 9: Graphical representation of heat losses

An example of the hourly average heat loss distribution in a typical week is shown in Figure 10 below. The variations are mostly a result of the differences in temperature during the days and nights. This will be managed by opening the spa for public bathing mostly during the day when temperatures are high and by closing during the nights when the temperatures are lower.

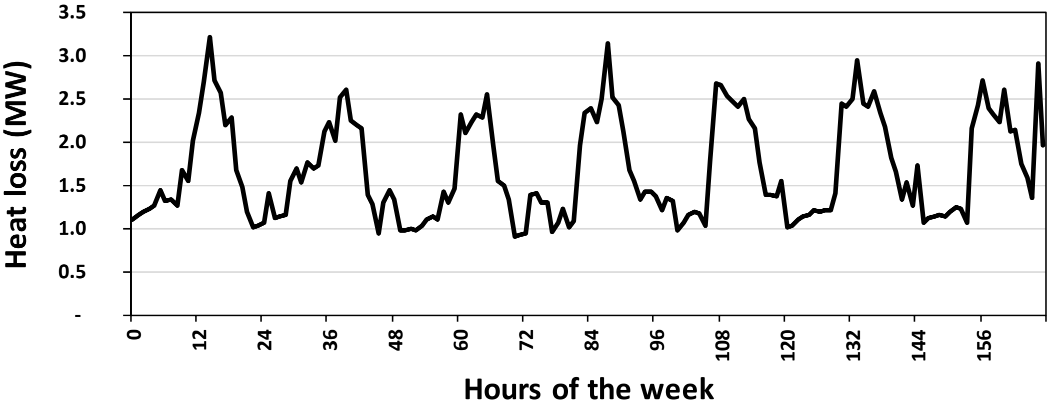

FIGURE 10: Hourly average heat loss distribution in a week

Figure 11 below shows the daily average heat loss distribution in the year while Figure 12 shows the load duration curve. A small part of the heat losses above the design conditions of the spa (2.2 MWt) is not expected to have a significant effect on the temperature of the spa since it is in only a few days of the year.

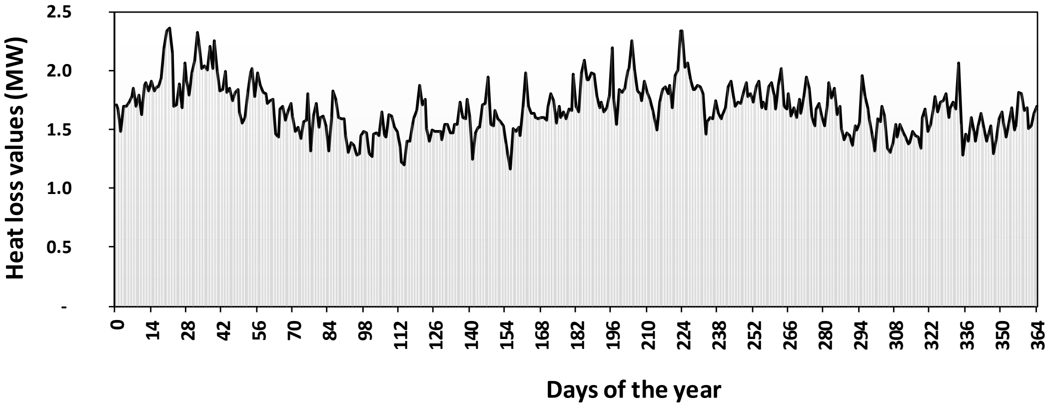

FIGURE 11: Daily average heat loss distribution curve in a year

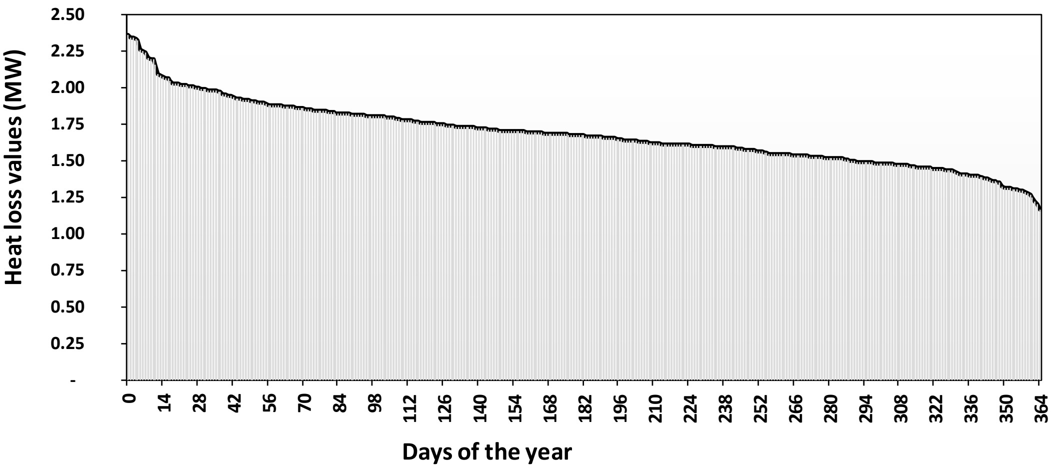

FIGURE 12: Yearly load duration curve for heat losses

Figure 13 is a representation of the layout of the geothermal spa and binary power plant.

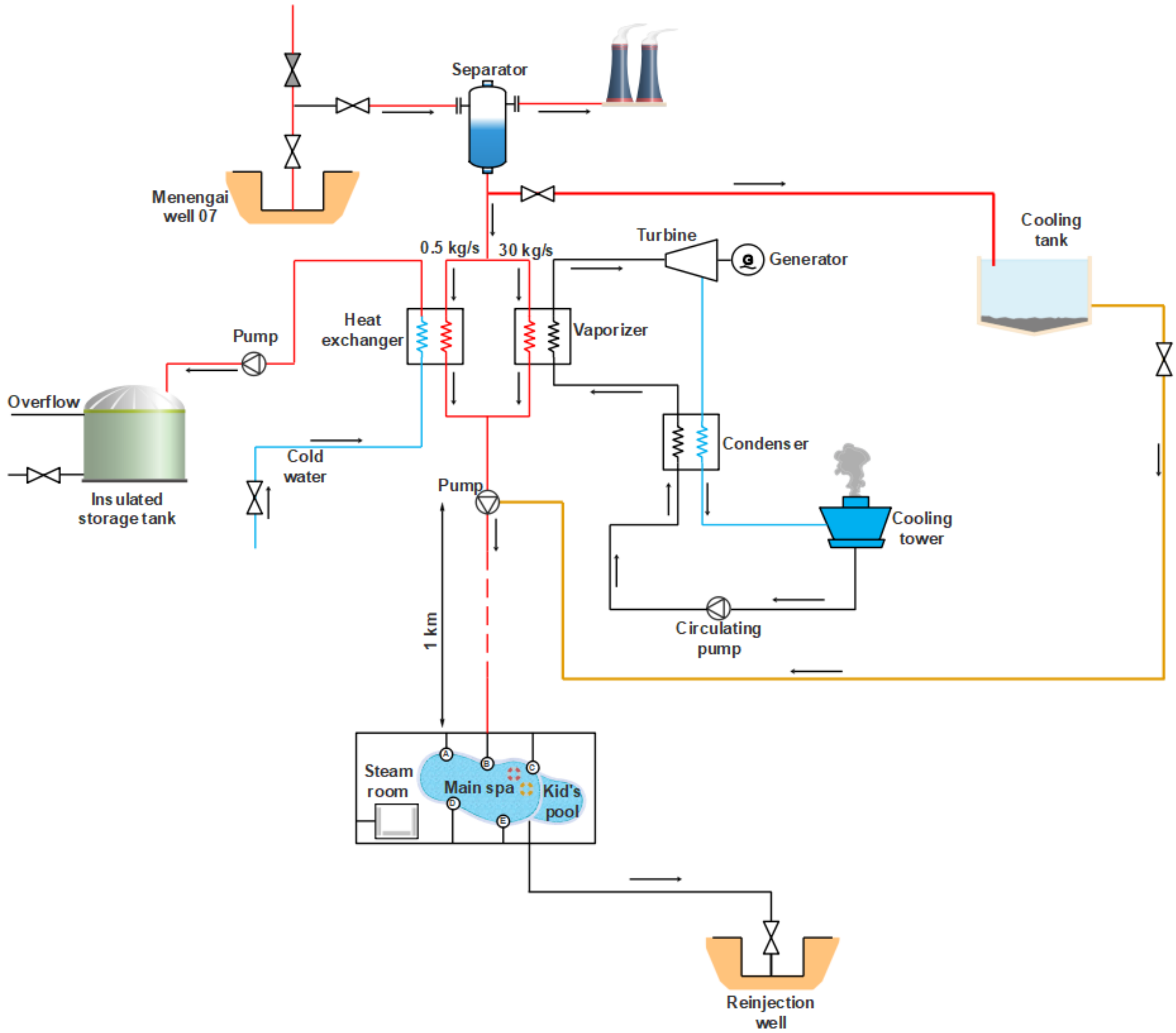

FIGURE 13: Project layout

4.4 Heating water for the showers

It is required that every guest takes a shower before and after bathing. It is assumed that each guest requires about 50 L of water. For a minimum of 200 guests per day, the water for the showers will be 1,000 L per day. This water will be heated by the geothermal brine through a heat exchange process and stored in an insulated tank. This will ensure a constant supply of hot water at relatively even pressure for the showers. There is potential for silica scaling and calcite deposition in the heat exchanger since its concentration is normally high in geothermal fluids and its solubility is temperature dependent (Ontoy et al., 2003). To mitigate the scaling a higher flow rate must be maintained during the heat exchange process and its temperature kept high (>88°C). Under these conditions' calcite scaling is not expected unless the brine is cooled below this temperature as has been observed in tests with brine from a nearby well in Menengai (Kipng'ok, 2011). It is also recommended that the heat exchanger will be made of corrosion-resistant stainless steel.

4.4.1 Design of the heat exchanger

Theory of heat exchangers

A heat exchanger is a device that transfers thermal energy from a hot fluid to a colder one without the two fluids coming into physical contact with each other. The two fluids must, however, come into thermal contact and heat can only flow from the hotter fluid to the colder one. Transfer of heat, therefore, involves convection in each fluid and conduction through the walls separating the two fluid (Cengel, 2008). Heat exchangers are useful for various applications such as heating a colder fluid using a hotter one, cooling a hotter fluid using a colder one, vaporising a liquid using a hotter one and condensing a gaseous fluid using a colder one. According to Thomasnet (2019), some of the factors that affect the selection of a heat exchanger are:

- The desired thermal output
- The type of fluids, fluid properties and the fluid flow rate
- Size
- Cost of the equipment

Classification of heat exchangers
There are many types of heat exchangers, broadly falling into two categories:

- Classification by type of construction (shell and tube or plate)
- Classification by type of fluid flow (recuperative, regenerative or evaporative)

The heat exchanger for this project will be designed according to the classification by the type of construction. The shell and tube heat exchangers (Figure 14) are the most basic where one fluid flows through a set of metal tubes while the second fluid surrounding the tubes. The colder fluid then absorbs heat from the hotter fluid. The two fluids can flow either in parallel or in opposite directions (counter-current flow).

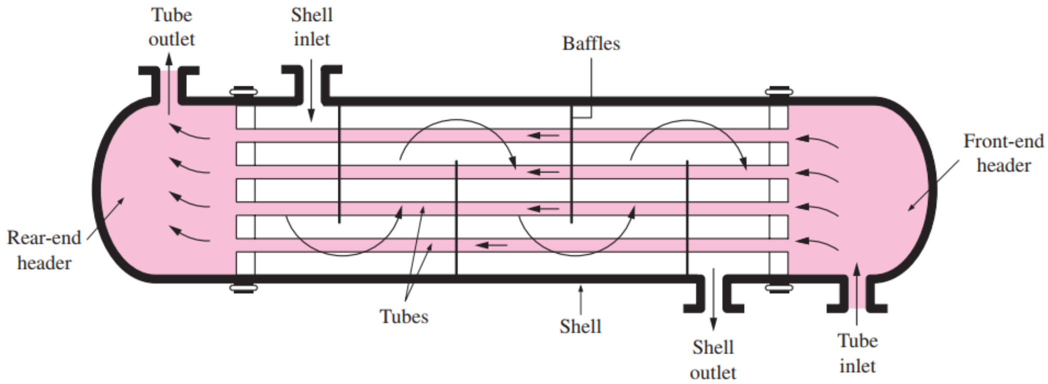

FIGURE 14: Shell and tube heat exchanger with one shell pass and one tube pass (Cengel, 2008)

In the plate heat exchangers (Figure 15), plates separate the two fluids which baffle inside the plates inducing a turbulent flow, giving the fluids a better capability of transferring heat between each other. These heat exchangers have the advantage in that they provide the fluids with a large surface area, hence a larger extent of heat transfer. They are therefore more compact, transfer more heat in comparison to the shell and tube heat exchangers and are, therefore, considered more efficient. A plate heat exchanger is chosen for this project.

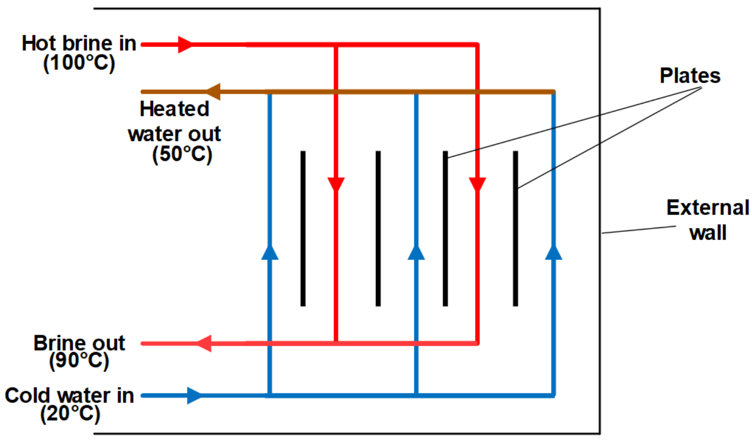

FIGURE 15: Principle of operation of the plate heat exchanger

The total heat transfer in a heat exchanger is dependent on:

i. Overall heat transfer coefficient U due to various heat transfer principles;
ii. Total surface area of the fluids;
iii. The inlet temperatures t_1 and outlet temperatures t_2 of the fluid.

Using the general heat flow equation (Equation 8):

$$Q = \dot{m} c_p \Delta T \tag{8}$$

where $\dot{m}$ = Mass flow rate (kg/s);
c_p = Specific heat of fluid at constant pressure (J/kg°C);
ΔT = Change in temperature in the heat exchanger (°C).

Heat provided by the hot fluid can be calculated using Equation 9 below:

$$Q = \dot{m}_h c_{ph} (T_{h1} - T_{h2}) \tag{9}$$

where $\dot{m}_h$ = Mass flow rate of the hot fluid (kg/s);
cC_{ph} = Specific heat capacity of the hot fluid at constant pressure (J/kg°C);
T_{h1} = Inlet temperature of the hot fluid (°C);
T_{h2} = Outlet temperature of the hot fluid (°C).

Heat absorbed by the cold fluid is calculated using Equation 10 below:

$$Q = \dot{m}_c c_{pc} (T_{c2} - T_{c1}) \tag{10}$$

where m_c = Mass flow rate of the cold fluid (kg/s);
c_{pc} = Specific heat capacity of the cold fluid at constant pressure (J/kg°C);
T_{c1} = Inlet temperature of the cold fluid (°C);
T_{c2} = Outlet temperature of the cold fluid (°C).

The total heat transfer rate in the heat exchanger is given by Equation 11:

$$Q = UA\Delta T_m \tag{11}$$

where U = Overall heat transfer coefficient between the fluids;
A = Effective heat transfer area (m^2);
ΔT_m = Logarithmic mean temperature difference (LMTD).

The logarithmic mean temperature difference (LMTD), calculated using Equation 12 below, is the temperature difference which, if constant, would give the same rate of heat transfer as actually occurs when the temperature difference varies.

$$\Delta T_m = \frac{(T_{h1} - T_{c2)} - (T_{h2} - T_{c1)}}{(ln(T_{h1} - T_{c2)} \,/\, (T_{h2} - T_{c1)}))} \tag{12}$$

The following design conditions are assumed:

Brine inlet temperature:	100°C
Brine outlet temperature:	90°C
Cold water inlet temperature:	20°C
Cold water after heating temperature:	50°C
Quantity of hot water required for bathing:	1,000 L for ten hours per day

The required mass flow rate of the brine for heating water for bathing would then be approximately 3,000 L every day. The calculated logarithmic mean temperature difference is 59.44°C and the product of the overall heat transfer coefficient between brine and the fresh water and the effective heat transfer area (UA) equal to 58.6 W/°C (summarised in Table 13).

TABLE 13: Design parameters for the heat exchanger

Parameter	Unit	Value
Brine flow rate	L/day	3,000
Logarithmic mean temperature difference (LMTD)	°C	59.44
Product of heat transfer coefficient and area (UA)	W/°C	58.6

4.5 Pipeline design

Designing the pipeline is a vital step in any project that has flowing fluids. The design needs to minimize the cost without sacrificing the quality and the desired function of the pipeline. The pipeline system is designed to operate at minimum pressure losses and without physical failure for the design life of the pipeline. Pipeline design is categorized into three broad categories:

- Low pressure pipes: the internal pressure is low or even non-existent. External loads govern these pipeline designs.
- Intermediate pressure pipes: in this category, both the internal pressure load and the external loads are of similar magnitude and must both be considered in the design.
- High pressure pipes: Internal pressure is very high and dominates the design.

The standard design process of a pipeline considers the topology, route selection, demand and flow analysis, optimization of the pipeline diameter, the thickness and pressure classes, mechanical stress analysis, thermal stress analysis and pump sizes and location. Major factors influencing the design and construction of a pipeline include (Nandagopal, 2007):

- Nature of the fluid and their properties;
- Length of the pipeline;
- Volume flow rate;
- Climatic conditions;
- Environmental constraints, codes, standards and regulations applicable;
- Terrain and medium traversed by the pipeline;
- Economics;
- Materials to be used.

Geothermal fluids contain different concentrations of dissolved minerals. Their nature and the surrounding environment must be considered when selecting the material to be used for the pipeline, valves, flanges and other fittings, taking into consideration the principles of corrosion and scaling. This is done with the objective of minimizing the total updated cost. A large diameter pipe decreases the pumping cost but results in increased capital cost, hence, an equilibrium needs to be established for an optimal design. Selection of the route for the pipeline involves the identification of constraints, avoiding undesirable areas and maintenance of economic feasibility of the pipeline. The pipeline design for this project is constraint by the maximum distance of 1 km between the spa and the source of the brine (Menengai well 07). The proposed location for the spa will be relatively even and sloping with minimal constraints. A straight-line pipeline is, therefore, designed. The use of a plastic pipeline capable of handling high to medium temperatures is considered since this would minimise the challenges of corrosion.

4.5.1 Pipeline diameter

The diameter of the pipeline mainly depends on the allowable pressure drop and fluid velocity. The proposed design aims at a pressure drop of about 0.5-1 bar/km and a brine velocity of about 1 m/s.

Using the Darcy-Weisbach equation (Ragnarsson, 2019), the pressure drop is calculated (Equation 13):

$$\Delta P = 810f * Q^2 * \frac{L}{D^5} \tag{13}$$

Assuming turbulent flow, the friction factor is calculated according to Colebrook-White equation (Equation 14):

$$\frac{1}{\sqrt{f}} = 1.74 - 2\log[\frac{2k}{D} + \frac{18.7}{Re\sqrt{f}}] \tag{14}$$

This equation can be approximated using the Nikuradse equation (Equation 15):

$$f = [2\log(3.715\,\frac{D}{k})]^{-2} \tag{15}$$

The Reynold's number Re is calculated as follows in Equation 16:

$$Re = \frac{\rho v D}{\mu} \tag{16}$$

where ΔP = Pressure drop (bar/km);
f = Friction factor;
Q = Volume flow (m^3/s);
L = Length (m);
D = Diameter (m);
ρ = Density (kg/m^3);
v = Water velocity (m/s);
Re = Reynold's number;
k = Roughness factor (m);
μ = Viscosity ($Ns/m^2 = kg/ms$).

Assuming that the maximum length of the pipeline is 1 kilometre, the brine flow rate is 30 kg/s, the density of the brine is 1000 kg/m^3, the dynamic viscosity (μ) is 3.67×10^{-4} kg/ms, and the pump efficiency is 70%, a pipe diameter of 0.178 m is designed with a pressure drop of 0.655 bar.

4.5.2 Pumping power

This is the total electrical power consumed by the motors of the pumps and fans in a system. They contribute to the annual project running cost. A pump provides sufficient pressure to overcome the operating pressure of the system to move the fluid at a required flow rate. The selection of a pump must take into consideration the length of the pipe, the size, fittings, type of fluid and pressure. It is, therefore, a function of the mass flow rate and the pumping power requirements.

Pumping power is defined by Equation 17 below:

$$P_d = \frac{H_d * Q * \rho * g}{\eta} \tag{17}$$

where P_d = Pumping power (W);
H_d = Pump head (m);
Q = Flow rate (m^3/s);
ρ = Density (kg/m^3);

g = Acceleration due to gravity (m/s^2);
η = Pump efficiency.

To maintain 5 bar pressure at the spa inlet and adding 5% to the calculated pressure drop to account for bends in the pipeline, the calculated size of a pump is then 139 kW.

4.6 Spa maintenance

It is necessary that a spa is maintained at high hygienic standards to avoid the risks and hazards associated with physical, chemical and biological factors. Outdoor pools face the additional risk of direct contamination by dust and animals like birds and rodents. Swimmers also introduce different contaminants into the water, for instance through faecal matter, skin shedding, hair and remains of cosmetics and perfumes. It is, therefore, recommended that the water is continuously replaced in the pool. However, this depends on the bathing load, defined as the number of persons in a pool at a given time. Table 14 below indicates the turnover period for different types of bathing waters highlighting hydrotherapy pools which would act as reference for a thermal spa.

TABLE 14: Turnover periods for different types of pools (WHO, 2006)

Pool type	Water turn-over period
50 m long competition pools	3-4 hours
Conventional pools up to 25 m long with shallow end	2.5-3 hours
Diving pools	4-8 hours
Hydrotherapy pools	0.5-1 hours
Leisure water bubble pools	5-20 minutes
Leisure waters up to 0.5 m deep	10-45 minutes
Leisure waters 0.5-1 m deep	0.5-1.25 hours
Leisure waters 1-1.5 m deep	1-2 hours
Leisure waters over 1.5 m deep	2-2.5 hours
Teaching/learner/training pools	0.5-1.5 hours
Water slide splash pools	0.5-1 hours

Accreditation to quality awards would act as one way to ensure that the spa is maintained at high international standards. For instance, the Blue Flag Standards, which the Blue Lagoon adheres to, specifies that bathing facilities must be free from plastics and must be equipped with waste management systems, must provide international amenities and clean water for its clients. It challenges local authorities and beach operators to achieve high standards in water quality, environmental management, environmental education and safety (Blue Flag, 2014). The standards implemented in Europe since 1987 and in areas outside Europe since 2001, provide detailed criteria for the required minimum standards for bathing facilities. The World Health Organisation (WHO) also provides guidelines to be followed when running of swimming pools and similar facilities with a primary aim of protecting the public health.

It is required that bathing facilities position lifeguards to assist bathers in distress.

4.6.1 Physical factors

Physical factors normally include the management of water and air quality in and around the spa. This is usually achieved through treatment, disinfection and filtration, pool hydraulics, addition of fresh water, cleaning and adequate ventilation of indoor facilities (WHO, 2006). Since no disinfection will take place in the spa, the physical control of the water quality will be done by circulation of the brine to ensure a healthy equilibrium in the lagoon. The design for the indoor facilities like shower rooms will incorporate adequate ventilation to ensure a good flow of fresh air. A sludge pump for sucking the brine from the spa bottom will be installed during construction. This will ensure that the spa remains clean and clear of silica that settles in the floor bottom. The spa will be cleaned once every two days without draining.

4.6.2 Chemical factors

Swimmers can be exposed to chemicals through ingestion, inhalation of volatile and aerosolized solutes and through dermal contact and skin absorption. The fluid in the spa will be constantly moving ensuring minimum exposure to the bathers in order to maintain highest levels of hygiene since no chemicals are added to the brine. However, material selection is critical due to challenges associated to scaling, corrosion and stain formation. The chemistry of the fluid for the spa will determine these levels. Chemical factors affecting the quality of water are shown in Table 15 below (Puetz, 2013):

TABLE 15: Allowed range for water quality

Chemical factor	Allowed range
pH	7.2-7.8
Total alkalinity	80-120 ppm
Calcium hardness	100-400 ppm
Iron (stain producing elements)	Nil
Total dissolved solids	250-1500 ppm

Water balance is the tendency of the water to form scales or become corrosive. It is determined by the total alkalinity, pH and calcium hardness alongside temperature. Maintaining proper levels go a long way in preventing scaling and corrosion. Silica scaling is a universal problem in most geothermal systems since the solubility of silica, which is common in geothermal fluids, decreases exponentially with decrease in temperature. While it has beneficial characteristic such as giving geothermal spas the blue milky colour and is good for the human skin, it can be a problem when it solidifies in pipelines and valves. As a preventive measure, further tests will be performed on the brine before it is used for bathing. As Table 3 shows, a preliminary check indicates that brine from the well does not comprise of chemical elements that would cause challenges in corrosion. Scaling will be controlled by how low the brine is cooled and by scrubbing the spa pipeline using high pressurized water.

4.6.3 Biological factors

Biological control includes sanitization and control of algae. The risk of illness and infection in a spa or related facilities is primarily associated either with faecal contamination from the bathers or from contaminated water or geothermal fluids (WHO, 2006). It is therefore possible to lower the risks by enforcing that all bathers take a shower before admission into the facility and by restricting the children to a pool that can easily be drained in case of an accidental faecal release into the water. Geothermal spas do not necessarily require addition of chemicals for sanitization since brine is usually self-cleansing. However, growth of algae must be controlled, otherwise the spa water would get an unpleasant green colouring and the surfaces become slimy. This will then be done by ensuring that the brine stays only for a short time in the lagoon and that cooled incoming hot brine is fed into the lagoon before it allows algae or other microorganisms to grow. Brine flowing into the spa flows inside a pipeline and is thus not exposed to dirt, particles and contaminants from the atmosphere, rainwater and wind. Sampling of water will be done according to the Blue Flag Standards or the World Health Organisation Standards to ascertain a clean and healthy bathing fluid. Table 16 below is an extract from the World Health Organisation guidelines for microbial testing of natural spas and hot tubs.

TABLE 16: Recommended routine sampling frequencies and operational guidelines for microbial testing (WHO, 2006)

Pool type	Thermotolerant coliform / E. coli	Pseudomonas aeruginosa	Legionella spp.
Natural spas	Weekly (<1/100 ml)	Weekly (<10/100 ml)	Monthly (<1/100 ml)
Hot tubs	Weekly (<1/100 ml)	Weekly (<1/100 ml)	Monthly (<1/100 ml)

4.6.4 Waste treatment

Sewerage and wastewater
Since all guests are required to shower before and most likely after bathing in the spa and are likely to use the rest rooms at least once, a sewerage system capable of handling at least 2,000 L of wastewater must be put in place. Wastewater and sewerage will be treated separately. The location must be in the direction of the wind from the spa and far away enough to keep the foul smell away from the spa. Areas around the spa and the parking must be constructed to slant outwards to allow storm water collection for disposal downstream into a drain field. The ground in Menengai is generally highly porous and disposal of liquid waste may not be a major challenge.

Brine reinjection
Unlike in Iceland where most geothermal spas began without reinjection, due to environmental regulations and the need to seal off the ground water sources from contamination, a Kenyan spa would require that all brine is disposed into a reinjection well. A nearby reinjection well downstream of Menengai well 07 will serve as a reinjection well.

5. MARKETING

The concept of marketing most geothermal spas is based on the traditional bathing practices of the population of its country even though they have potential to attract a wide variety of people (GeothermEx, 2000). Another factor for marketing is the promotion of relaxation (most spas are associated with reduction of stress) as well as health and fitness and most spas offer various athletic equipment and activities.

Tourism is currently Kenya's largest foreign exchange earner and one of the major contributors to the country's gross domestic product (GDP). Main tourist attractions are the renowned game parks and beaches. The Menengai caldera is a favoured location for a spa since it has a serene and peaceful environment and is home to beautiful flora and fauna. It is near Lake Nakuru national park, home of flamingos and the first successful Rhino sanctuary, is near Lake Bogoria which has spectacular geothermal manifestations, and is located midway between Nairobi, Kenya's capital and Maasai Mara, one of the main national parks in the country. The Lord Egerton castle, a splendid piece of architecture with green lawns built in the 1930s which is only 15 kilometres away from the city, is also a well-known tourist attraction. The caldera offers a panoramic view of the surroundings including the geothermal activities and the beautiful Nakuru town. It would be profitable, therefore, to package the Menengai caldera, the Lake Nakuru national park and the Lord Egerton castle as an ecotourism project, partner with municipalities, travel agents and associations, and hotels hosting tourists and local guests to attract more visitors to visit the spa. A local all-year round ticket could be offered to the local population at an affordable price as an incentive to draw them into the spa. Small children accompanied by their parents or guardians would be allowed free entry at least until the spa becomes popular and the price plan is reviewed.

A small restaurant will be constructed within the spa premises with a possibility of expansion. A health institution would also be incorporated which can take advantage of the health benefits for the treatment of their patients and in a learning facility guests can be educated on the prevention of various lifestyle diseases. Since sport-related tourism has gained a lot of popularity in some countries, their inclusion adds value to the spa attracting a wider group of tourists.

6. FINANCIAL ANALYSIS

The financial analysis is the assessment of the viability, performance and profitability of a project or a business venture. It is a valuable tool for decision-making on whether to begin the construction and implementation or, at a later stage, whether to continue the development of a project. Profitability of a spa venture highly depends on the marketing of the spa, since the cash flow depends on the number of customers. Table 17 below is a summary of the activities and facilities that need to be considered for the construction of the spa and their expected costs:

TABLE 17: Assumed construction costs for the spa

Item	UoM	Qty	Unit cost (USD)	Total cost (USD)
Permits	LS	1	500	500
Preliminary tests	each	3	10,000	30,000
Binary power plant	LS	1	900,000	900,000
Excavation	m^3	3300	5	16,500
Filling	m^3	2750	15	41,250
Reinforcement	m^2	500	100	50,000
Construction of the buildings	LS	200	500	100,000
Construction of the parking lot	m^2	1500	50	75,000
Construction of the spa floor and side walls (with side benches)	m^2	80	250	20,000
Operation equipment and accessories (pumps, valves, temp. regulators, flow meters)	LS	1	100,000	100,000
Brine pipeline and insulation	m	1000	100	100,000
Storage tank	each	1	4,000	4,000
Water pipeline	m	500	100	50,000
Rubber fabric for the spa floor	m^2	300	10	3,000
Heat exchanger	LS	1	7,000	7,000
Spa drink service area	m^2	10	500	5,000
Medical facilities	LS	1	20,000	20,000
Sewerage treatment system	LS	1	50,000	50,000
Sub-total				**1,572,250**
Contingencies	LS	1%	20%	314,450
Sub-total 2				**1,886,700**
Engineering design			15% of total	283,005
Supervision cost			12% of total	226,404
Grand total				**2,396,109**

LS: Lump sum

Different tools can be used to assess the financial viability of a project, such as the Net Present Value (NPV) and the Internal Rate of Return (IRR). The Net Present Value (NPV) is the difference between the value of cash inflows and the value of cash outflows in each period, while the IRR is the discount rate that would reduce the NPV of an investment to zero. NPV is calculated using Equation 18 below:

$$NPV = \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} \tag{18}$$

where n = Total number of years (project life);
t = Number of years;
C_t = Net cash inflow – outflow in a year;
I = Discount rate of return.

Using the assumptions in Table 18 below, a positive NPV would be realised after 6 years (Figure 16) and a value of USD 3,231,656 would have been obtained in the last year of the project. It is assumed that the pool will be in operation for 360 days in a year with 5 days for maintenance.

TABLE 18: Assumptions for the financial analysis of the spa

Item		Value
Construction cost (USD)		2,396,109
Annual operational costs (USD)		100,000
Number of tourists per day	Local	150
	International	50
Entrance fees (USD)	Local	5
	International	25
Number of days in a year the pool is in operation		360
Project life (years)		25
Total annual income (USD)		**720,000**

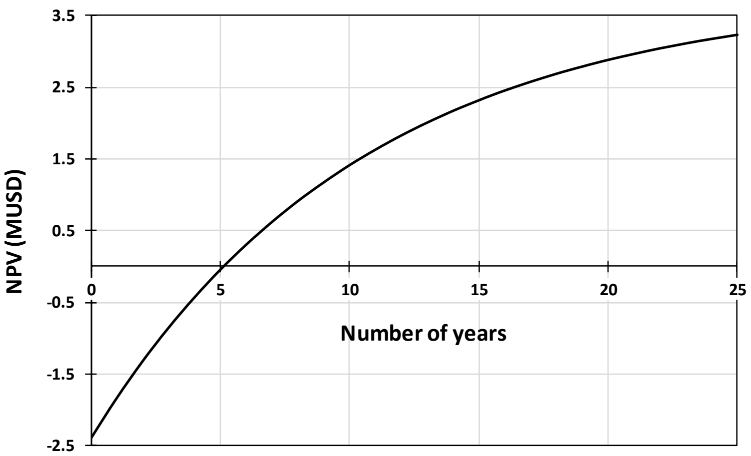

FIGURE 16: Net present value for the project

The calculated IRR for this project is 25.8%.

A sensitivity analysis was carried out by varying the various parameters that affect the spa profitability by increasing and decreasing the size of each parameter by 10 and 20%. The varied parameters are:

- Capital costs,
- Local guests,
- International guests,
- Discount factor,
- Operational costs.

Table 19 below shows the results of the sensitivity analysis:

TABLE 19: NPV results from sensitivity analysis (USD)

Variations / parameter	Capital cost	Local guests	International guests	Discount factor	Operational costs
-20%	3,710,878	2,741,496	2,414,722	2,466,637	3,413,197
-10%	3,471,267	2,986,576	2,823,189	2,825,373	3,322,426
Reference	3,231,656	3,231,656	3,231,656	3,231,656	3,231,656
10%	2,992,045	3,476,736	3,640,123	3,693,890	3,140,885
20%	2,752,434	3,721,816	4,048,589	4,222,252	3,050,115

The results show that an increase in the discount factor has a large negative influence on the net present value (NPV). An increase in the capital costs also has a negative influence on the NPV. An increase in the number of local and international guests leads to a gradual increase in the profitability of the spa. Operational costs should be kept at the minimum, since an increase reduces the spa's profitability. Figure 17 below is a graphical representation of the results. The larger the gradient of a curve, the larger is the influence of the corresponding parameter on the NPV.

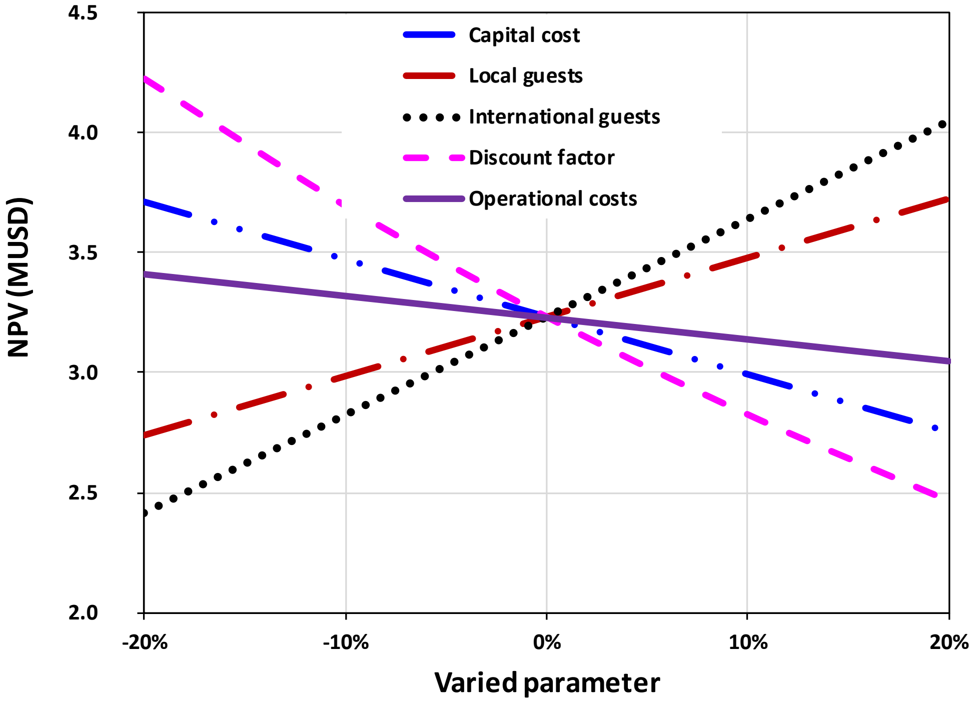

FIGURE 17: Sensitivity analysis for the project

7. CONCLUSIONS AND RECOMMENDATIONS

Various considerations in the design of a conventional geothermal spa were assessed and proven viable for well 07 in the Menengai geothermal field. The brine produced by this well alone can power a small binary power plant and the residue energy in the brine can be used in a geothermal spa. A 1,000 m^2 geothermal spa alongside a 100 m^2 children's pool was considered in this study which could comfortably be operated using the current flow rates from the well, even leaving room for expansion. Provision was made for tapping brine from the main reinjection line in the future. Marketing of the spa must be emphasized, and high standards maintained in order to attract and retain clients in the spa. However, Menengai is already a renowned area for hiking and is located in a strategic location because it is close to many tourist attraction centres like Lake Nakuru, the Lord Egerton castle and is midway the country's capital city and the renowned Maasai Mara game reserve, making the spa an even more viable venture.

It is, therefore, recommended that a geothermal spa of this size is constructed and expanded as clientele grows and that power plants are constructed in the geothermal field. This would also open other direct uses of geothermal energy for which there is great potential in Menengai and other geothermal fields in Kenya. Further tests on the chemistry of the fluids and its suitability for bathing is recommended prior to opening the spa for bathing by the public.

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NOMENCLATURE

IDO	= Industrial diesel oil
HFO	= Heavy Fuel Oil
ODP	= Ozone depletion zone
GWP	= Global warming potential
RH	= Relative humidity (%)
BP	= Barometric pressure (mbar)
USD	= United States Dollar
MUSD	= Million United States Dollar
NPV	= Net present value
UoM	= Unit of measure
Qty	= Quantity
WHO	= World Health Organisation

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