Direct Use of Geothermal Energy: Feasibility Study for the Construction of a Geothermal Spa in Menengai, Kenya

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ABSTRACT

Geothermal energy, heat from the interior of the Earth, has been utilized by mankind since time memorial, with hot springs and hot pools being used for bathing, health treatment, cooking and heating. The resource has also been used for producing salts from brine. In Iceland, natural hot springs have been used for bathing for a long time, but since early the last century, outdoor swimming pools have gained popularity, and are today part of daily life of a large population in many parts of the world where geothermal resources exist. In Kenya, the use of hot springs is limited to only two facilities; the natural Lake Bogoria Spa, and a geothermal spa recently constructed in Olkaria by the Kenya Electricity Generating Company (KenGen) utilizing brine tapped from a reinjection line. In 2015, a Direct Use Demonstration Project was launched in the Menengai Geothermal Field by Geothermal Development Company, GDC, and is being used to showcase modern direct applications of geothermal energy. GDC is exploring the possibility of setting up a geothermal spa in the same field to enhance direct utilisation of geothermal energy and also add value to the tourism industry in the Menengai Geothermal Prospect. This paper, on a feasibility study, assesses suitable size, quality, capacity and cost, and has come up with a schedule for its construction while ensuring international quality requirements.

1. INTRODUCTION

The word "spa" traces its origin to a town near Liege in southern Belgium near the German border where an iron master used a spring of iron bearing water in 1326 to cure his ailments. He founded a health resort at the spring called Espa, meaning fountain in Wallon language. Espa became so popular that the word in English spa became the common designation for similar health resorts around the world (Lund, not dated). Natural spa is the term used to refer to facilities containing thermal and/or mineral water, some of which may be perceived to have therapeutic value and because of certain water characteristics may receive minimal water quality treatment (WHO, 2006). The water with certain mineral constituents and often warm gives the spa meaning from one or more of the following points of view:

- Religious, mythical and symbolic
- Social, political and economic
- Aesthetic, artistic, literary
- Philosophical, scientific, technological and medical

The unique elements of a spa tend to attract more people than the swimming pools. Steam baths and saunas have also been designed to utilize geothermal fluids. Relaxing in these facilities is associated with enormous health benefits including improved blood circulation, cleaning and rejuvenating the skin, eased muscle tension, promotes feeling of relaxation and well-being and enhances detoxification processes (Kinyanjui, 2013).

Geothermal Development Company has been involved in drilling wells in the Menengai geothermal prospect since 2011. More than 30 successful wells have been drilled, most of which are high enthalpy wells, suitable for electricity generation. Few wells are of low enthalpy and thus more suitable for non-electrical uses commonly referred to as direct use applications. Some of the low enthalpy wells are MW-03 and MW-07. The two wells produce two-phase fluids with a high percentage of geothermal water (brine) as compared to steam. A spa usually requires a considerably high flow rate of brine so as to achieve the desired results. Therefore, these two wells can be a source of brine to be used in the spa. There are plans to construct a 105 MWe power plant in Menengai with three units, each generating 35 MWe. Conventionally, the fluid goes through a separator before being channeled to the turbine. The separation process yields steam which is directed to the turbines while water with a considerable high thermal energy can be used in a spa.

2. CONSTRUCTION OF A SPA IN THE MENENGAI GEOTHERMAL FIELD

2.1 Assumptions

In our model of the Spa construction, the following assumptions will be made:

Table 1: Assumptions for Construction of the Spa

Assumption		Justification
Location	The facility will be located inside the Menengai Geothermal Prospect	The Menengai Caldera has a unique and attractive view
Resource	Brine will be sourced from either MW-07, power plant or MW-03	It is expected that the sources will meet the required flow rates, temperatures and pressures
Chemistry	Scaling problems will be manageable, algae problems will be contained and water is suitable for bathing. This can be tested prior to construction of the spa.	The existing chemical analysis does not indicate that this water will be more problematic than from similar brine based spas.

2.2 Geothermal Spa Design

2.2.1 Market Considerations

Knowing the target client is an inseparable part of building a spa resort. This determines the quality of service, the price levels and the size of a pool needed. There are two types of customer base who are of importance; the domestic and international tourists. Local population is expected to be more reliable all year round, whilst foreign tourists though seasonal, are expected to contribute high revenues. Table 2 summarizes some key customer bases for the proposed spa.

Table 2: Potential Clients expected to visit the spa

Location	Approximate distance from the proposed Spa	Comment
Nakuru town	30 km	Town of approximately 300,000 residents
Maasai Mara	150 km detour for tourists	Can be used to tap more tourists
Naivasha town	90km	It has a wildlife resort which can help boost the number of tourists visiting the spa on referral basis.
Nairobi	190 km	City of around 5 million residents

The return trip distance between Nakuru town and Menengai is approximately 60 km. This is a considerable effort for tourists to travel to such a location from Nakuru town, and therefore the quality and experience the guests get must be worth the trip plus the ticket price. Emphasis on quality should therefore be of the highest consideration. Guests travelling this long will also be more willing to pay a little more on amenities to make the trip more worthwhile. Typical minimum requirements would therefore mean warm showers; shampoo and conditioner included, service of drinks in the pool and some minimal food services outside the pool. These extras can be very important as in the Blue lagoon in Iceland, they make up about 30% of the total income, which is especially valuable as the investment cost of providing these services is much lower than for the pool facilities. It is worth noting that most Kenyan families go out to mostly entertain their children, and is therefore necessary to have inclusion of children entertainment facilities to encourage families enjoy extra services from the spa. A typical price plan is shown in the following table.

Table 3: Proposed price plan

Item	Domestic tourists	International tourists
Travelling cost (from Nakuru town)	6 USD /person	15 USD /person
Entry Price	5 USD/person	20 USD/person
Drinks and food	5 USD/person	10 USD/person
Total price	**16 USD/person**	**45 USD including travel**

With a target of 50 guests per day; 70% local and 30% international, a projection of about Ksh. 127,205 (1,235 USD) can be achieved per day for a start. Achieving this target may not be easy, especially in the beginning, as swimming in spas is uncommon for most Kenyans. One way to build the culture would, therefore be to lower the price initially, and then gradually increase as the culture catches on and the 50 guest target is met. A lesson learned from the Blue lagoon business model, is the inclusion of a drink in the ticket price. This may encourage guests and justify a higher ticket price. Bus trips may furthermore help lower the travel cost of guests, and seasonal pricing may encourage the local population to visit less during the tourist seasons. This is a scenario spa entry charge where the locals are increased during peak international tourist seasons. It is proposed that GDC partners with the government and private agencies dealing with tourists so as to boost the number of guests visiting the spa.

2.2.2 Location of the Spa

The proposed spa will be located in the Menengai Caldera which has an attractive view, is served with 3-phase electricity power supply, fresh water and all-weather access roads.

Three options will be considered for sourcing of brine:

i. Separator station and power plant steam condensate

ii. Menengai Well 7 (MW-07)

iii. Menengai Well 3 (MW-03)

- **The Characteristics of Menengai Well 03 (MW-03)**

The well is drilled to a depth of 2100m with a wellhead pressure (WHP) of 1.6 bar and water flow of 40t/hr. and steam flow of 20t/hr (Figure 1).

Figure 1: Technical data of MW-03

- **The Characteristics of Menengai Well 07 (MW-07)**

This well has an average well head pressure of 2.4 bar, at a mass flow rate of 140 t/hr. on average. The well is dominated by water with a very minimal steam flow. The table below shows a comparison of the parameters at the blue lagoon, Myvatn Nature baths, Menengai well 3 and 7.

Table 4: Comparison of geothermal fluids with existing successful geothermal spas

Parameter	Unit	Blue lagoon (Iceland)	Myvatn Nature Baths (Iceland)	MW-07 (Menengai)	MW-03 (Menengai)
pH		7.5	9.2	9.2	8.6
SiO_2	mg/kg	251	552	273	362
TDS	ppm	26000	900	7773	6580
WHP	bar-g	-	-	2.45	0.7

Brine from MW-03 and MW-07 has similarly high SiO_2 as Blue lagoon and Myvatn Nature Baths, giving it the attractive blue color. The salinity is, however, similar to Myvatn Nature baths, but the level of CO_2 is much higher, which may lead to some calcite scaling. Based on the data from the drain ponds, scaling is presumed to be manageable.

2.2.3 Type of Spa

A thermal spa is a health spring considered to have health and beauty benefits. As a result, the chemical composition of the water must be established prior to people bathing to ensure that minerals dissolved in the water do not have harmful effects on the human skin. Similarly, the temperature must also be monitored to at most between 37°C and 40°C to protect people from getting scotched. However, bath tubs are also constructed with their water even up to 44°C.

The operation of the spa this type is such that brine will flow into a conical shaped reservoir. The reservoir is open and at atmospheric pressure, therefore, a considerable energy is to be lost from the tank. Brine from the reservoir is to be directed into mixing tanks, which will allow mixing of the brine with colder brine from the spa. A thermostat is to be installed adjacent to the mixing chamber in order to allow for temperature regulation that will ensure that the pool temperature does not exceed 38°C. A signal will be sent to the main valve which will let in or cut the water flow accordingly thus ensuring efficient regulation of temperatures in the spa as is required. The spa will have different sections which will allow brine to progressively lose heat before it gets to the drain. This will dictate a continuous flow of brine from the source point.

The high quality of temperature regulation is of essence to the customer. However, this technology is not common in the Kenyan swimming pools and spas and this may require sourcing external expertise to actualize standard control systems. Material selection of the brine pipelines will largely depend on the chemistry of the geothermal fluids, the pressures and the required flow rates to the spa, and need to tolerate mechanical cleaning methods. Figure 2 shows the proposed design layout.

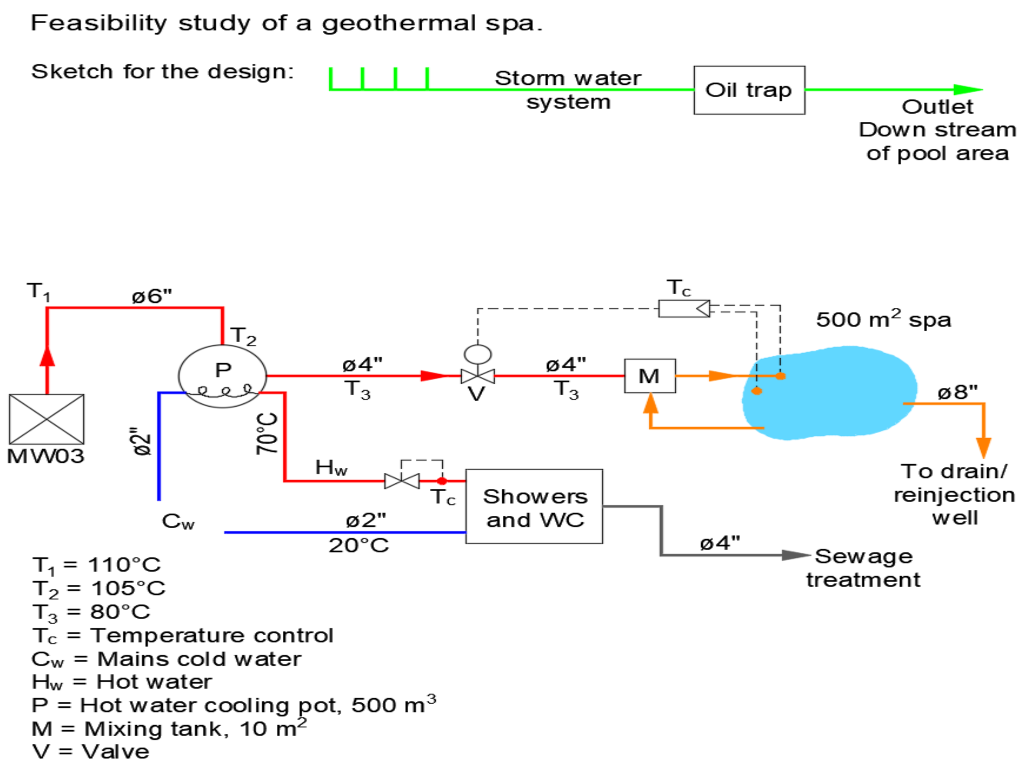

Figure 2: Pictorial sketch representation of the proposed spa

2.2.4 Size of the Spa

The size of the proposed geothermal spa will be determined by the following factors:

i. The desired number of customers

ii. The availability of brine (geothermal water)

iii. The quality of water in the spa

iv. Energy requirements

The sizing of the spa in Menengai geothermal field will be based on the existing spas in Iceland. The Blue Lagoon geothermal spa has an area of 8000m^2 and attracts an average of 3,000 guests per day. For the proposed spa in Menengai, 500m^2 is expected to host 50 guests per day if all the parameters will be like those of the Blue Lagoon. Replacement of water at every 24 hours will improve on the water quality in the spa by removing impurities and limit growth of algae which can discolor the spa. Using the same principle of the 8000m^2 Blue Lagoon which hosts about 700 to 1000 at a time, then a 500m^2 spa could accommodate 50 to 70 guests at a time for same quality standard.

For this size spa a changing room of about 100m^2, a reception area and waiting bay of about 100m^2 are suitable. The spa this size should have 50 lockers, 7 showers and at least 2 toilets on each the male and female sides. A parking lot of 1000m^2 would be suitable for the proposed 500m^2 geothermal spa.

2.2.5 Energy requirements

When estimating the energy requirements, the heat loss due to evaporation, convection and radiation are considered, and compared with the energy source (see Appendix 1). Calculation was conducted where values for varying ambient temperature and wind speed for a geothermal spa of 500m^2 at 38°C at different brine flow rates of 110°C hot brine were considered.

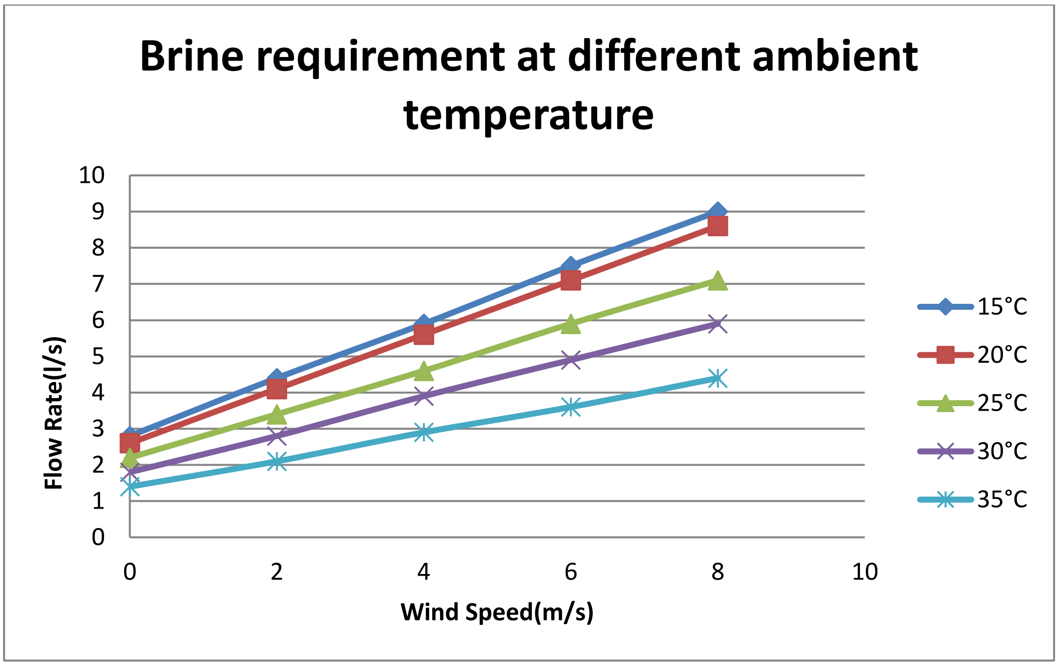

Figure 3: Brine requirements at different ambient temperatures

The energy calculation shows that under most circumstances, the energy of the brine is more than enough to maintain 38°C in the pool unless in the most extreme cases. This means that additional cooling may be required to maintain the sufficient water replacement rates. The conical shaped tank, helps removing the surplus energy, and is therefore favorable for these circumstances.

2.2.6 Waste treatment

- **Sewage Treatment**

Sewage and shower water need to be treated separately. Each guest will shower before and after going to the pool and is likely also use the restrooms. It is assumed that each guest will therefore use about 75 liters of water during the visit. Thus the sewage treatment facilities need to be able to handle 15,000 liters of waste water per day.

In order to minimize the risk of mosquitoes breeding, and bad smell in the pool area, the sewage treatment should be located some distance from the pool, and preferably water treatment should be handled underground using a septic tank treatment system and septic drain field.

- **Pool water reinjection**

Main pools in Iceland began without reinjections, relying on water seeping into the ground in settlement pools. Both the Myvatn Nature Baths and the Blue Lagoon do however now use reinjection. In the Myvatn Nature Baths, all the water is re-injected through 200m deep reinjection well. No problems have risen with clogging due to scaling, but the drill hole did intersect a large underground cavity. To manage reinjection challenges in Kenya, adequate geological studies have to be carried out. If cracks and crevices are found, disposal of the used brine from the spa will be easier, otherwise a reinjection well has to be drilled or identified.

- **Storm water disposal**

All storm water from the parking lot and pool area will be collected in a drain system and disposed off downstream. The parking and the pool surrounding should slant outwards from the spa to avoid inflow of storm water.

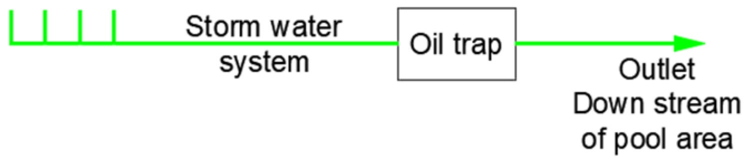

Figure 4: Storm Water Disposal

2.2.7 Operation and maintenance of the spa

Special expertise will be required to enable efficient operation of the spa. It is therefore proposed that a public private partnership be adopted. GDC is the owner of the resource and thus a private company may construct a spa and its accompanying facilities. Other unforeseen maintenance challenges such as scaling cannot be quantified until the project is operational for some time. However, scaling mitigation measures must be put in place.

Geothermal pools are not disinfected. It is therefore not easy to control microbial growth and thus poses potential hazards. Water characteristics need to be monitored during operation, in order to ensure a healthy environment. World health organization (WHO) has published operational guidelines for sampling for microbial testing during normal operation (WHO, 2006). Some of these figures are quoted in Table 5.

Table 5: WHO Pool Operation Guidelines

	Thermo tolerant coliform/ E.coli	**Pseudomonas Aeruginosa**	**Legionella spp.**
Frequency	Weekly	Weekly	Monthly
Limit	<1/100 ml	<10/100 ml	<1/100 ml

In addition, special care may be required to control the growth of normal algae, which may discolor the pool during sunny days. This can be achieved with higher water flow, and more frequent water replacement. Emphasis need to also be put on keeping all surfaces clean as this they may cause contamination. Floors do, therefore need be cleaned constantly. Lifeguards need to be on watch in the pool at all times to ensure the safety of all the guests. A pool of 500m^2 requires about 10 staff members for its daily operation. This includes 3 lifeguards at the pool, 1 receptionist, 2 guards in the locker room and 4 others providing various services including, security, cleaning and selling beverages in the pool.

2.2.8 Scope of Work

The spa facility will entail the construction of 500 m^2 spa lagoon, with benches or sitting provisions along 30% of the sides. Surroundings will be naturally formed using lava rocks. The spa building will include changing rooms and shower area for both genders, each with two restrooms and 7 showers. A reception, a 50m^2 waiting area, staff and equipment area of 50 m^2

each will be provided. Two additional restrooms will be availed to meet the requirements of the anticipated number of staff to operate the spa. The area around the pool is expected to be tiled, with benches, sunscreens and tables. A 10 m^2 beverage service will be located in the lagoon at one side while a 1000 m^2 parking lot will be located in front of the pool. Lighting will be provided in all outdoor areas.

Brine pipeline to the spa will be put in place from the source point. A 150m^3 hot water reservoir will be constructed to hold brine between 90ºC and 110 ºC. The reservoir design will be such that it will allow for the loss of heat from the brine as is desired before it gets to the spa. Mixing tanks and thermostats will be provided to ensure effective temperature control in the spa.

The sewage treatment which will consist of a concrete septic tank and a drain field will be provided. The spa water will be disposed of through a 6" diameter reinjection well. The storm water drain system will be located in the parking lot and pool area. The pool will be equipped with medical equipment and preliminary tests will be conducted on the brine during the project preparation phase.

2.2.9 Financial Evaluation of the proposed spa

The following assumptions are considered (see Appendix 2 for detailed cost estimates):

Table 6: Assumptions on the Financial Evaluation

Item	
Estimated Construction Cost	USD 339,805
Financing	
Equity	USD 79,087
Borrowing (Loans)	USD 242,718
Sources of Income	
International tourists/visitors:(average)	30 per day
Domestic/local tourists (average)	40 per day
Entry fee to the spa facility	USD 9.71
Estimated annual revenue	USD 203,883
Operating costs(Fixed + Variable costs)	USD 71,877
Annual Fixed costs	USD 58,252
Annual Variable costs	USD 13,625
Taxes 30%	30%
Discount Rate 10%	10%
Construction period	1 year
Interest Rate 9%	9%
Design life of the spa	25 years
Straight line depreciation	> 25 years

From the above assumptions, a financial model was used to calculate the Internal Rate of Return (IRR), Payback Period and Net Present value (NPV) of the investment on the Spa.

The findings were as follows:

IRR = 19%

NPV= USD 139,713

Payback Period = 4.4 years

The IRR is more than the interest rate while the NPV is positive, therefore the Spa investment is feasible and is expected to breakeven in approximately 4½ years.

2.2.10 Discussion and Conclusion

The development of a spa can be a game changer in the direct use applications of geothermal energy. The Icelandic blue lagoon facility attracts about one million visitors while the Myvatn Nature baths receives about two hundred thousand visitors a year. The two recreational facilities have an income of more than 60 M USD and 10 M USD respectively. The spa is expected to create employment opportunities from the hospitality, tourism, travel agencies and other technical personnel. This may transform the economic development in the Kenya. To achieve this, a full feasibility study has to be carried out. The pertinent questions are; does the Menengai field have the required technical aspects that meet a standard spa and are they sustainable? The other main concern is the number of visitors who are and will be willing to use the facility. It is recommended that the full feasibility incorporate the experts in spa facilities who have been involved in such successful projects.

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APPENDICES

Appendix 1: Energy Balance Calculation of the Spa

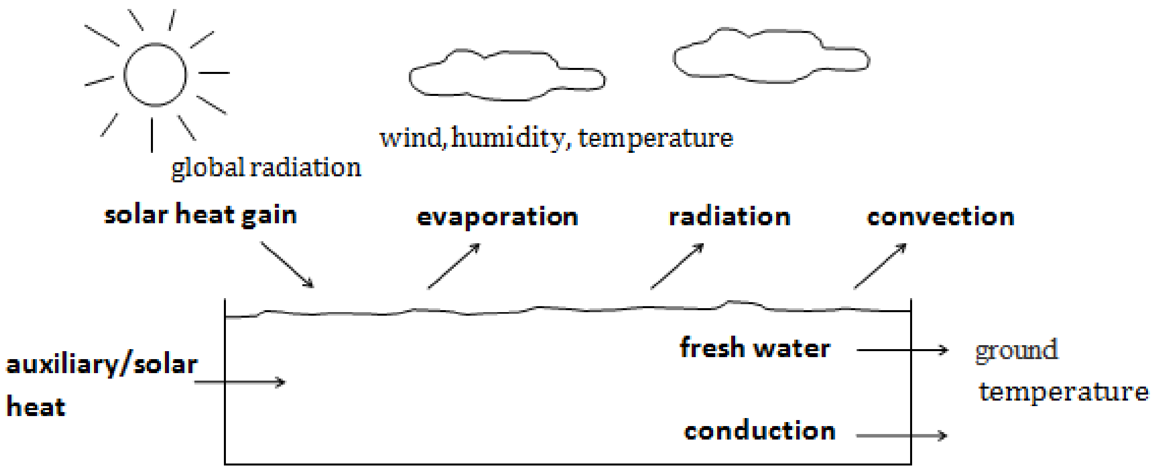

Figure 5: Energy Balance

Evaporation heat loss

Rinsha-Doncenko formula:

$$Q_e = (1.56K+0.7v) *(e_w-e_a) *4.19$$

Where:

Qe = Rate of heat loss by evaporation (W/m^2)

e_w = partial Pressure of steam at the surface (mbar), 1kpa=10mbar

e_a = partial Pressure of steam in air (mbar, Relative humidity considered

v = Wind speed at 2m height from the level of the ground (m/s)

K = Empirical Coefficient ($W/m^{2\circ}C$)

$$K = 0.93+0.04(T_w-T_a)$$

Where:

T_a = Ambient Temperature

T_w = Water Temperature

Convection heat loss

$Qc = h_c(T_l-T_a)$

Where:

Q_c = Rate of heat loss by evaporation (W/m^2)

T_l = Temperature of pool water °C

T_a = Ambient temperature °C

h_c= Convection heat transfer coefficient (W/m^2)

$h_c = (K+0.45*v) *4.19$

Pool heat loss = heat loss from (evaporation + convection + radiation)

$Qloss = Q_e + Q_c + R$
Where:

Radiation = %

R = Radiation = $(Q_e + Q_c)$ *percentage

For Energy balance,

Energy In = Energy Out

$Q_{loss} = \Delta Q_{in} - Q_{out}$
Energy balance calculation: Heat energy = Heat loss

Example:

For brine at 110°C flowing to a pond which is at 37°C,

Ambient Temperature = 21°C

Wind speed = 4.8 m/s

Relative humidity = 60%

Calculation of the flow rate is as follows:

From the steam tables:

Enthalpy of water at 110°C = 461.3 kJ/kg, and at 37°C = 154.9 kJ/kg

Therefore; change in enthalpy ΔH = 306.4 kJ/kg

But kJ/kg = kW/ls^{-1}; therefore,

ΔH = 306.4 kJ/kg = ΔH = 306.4 kW/ls^{-1}

Calculated heat loss in the spa = 1,643.873 kW

Therefore, brine flow rate = Calculated heat loss in the spa /ΔH

= 1,643.873 kW / 306.4 kW/ls^{-1}

= 5.37 l/s

Appendix 2: Detailed Cost Estimates for Construction of the Spa

COSTING					
	Unit of Measure	**Qty**	**Unit Cost (USD)**	**Total Cost (USD)**	**Total cost(KES)**
Building / Construction Permit	No. of permits	1	500	500.00	51,500.00
Earthwork: excavation	m^3	600	6	3,600.00	370,800.00
Earthwork: fill material	m^3	500	6	3,000.00	309,000.00
Reinforced concrete floor for the spa	m^3	600	8	4,800.00	494,400.00
Concrete for Changing/Shower rooms/Indoor waiting area	m^3	400	6	2,400.00	247,200.00
Concrete for parking lot, reception and staff rooms	m^3	1500	6	9,000.00	927,000.00
Hot water pot (8m diameter, with bottom, foundation and lid)	Lump Sum	1	15,000	15,000.00	1,545,000.00
Reinforcement bars	Lump Sum	1	200	200.00	20,600.00
Support walls and roofing for all buildings	Lump Sum	1	200	200.00	20,600.00
Preliminary tests	Lump Sum	4	250	1,000.00	103,000.00
Equipment Operation accessories (Pumps, Valves, Flow metres, Temperature Regulation)	Lump Sum	1	30,000	30,000.00	3,090,000.00
Brine pipelines with insulation	m	300	100	30,000.00	3,090,000.00
Water Pipelines	m	400	100	40,000.00	4,120,000.00
Sewage treatment plant	Lump Sum	1	5,000	5,000.00	515,000.00
					-
Construction of seating / relaxing bay inside the spa + supporting wall	m	50	20	1,000.00	103,000.00
Mixing tank		2	1,014	2,028.00	208,884.00
Overhead bridge	No.	2	2,000	4,000.00	412,000.00
Rubber Fabric for the spa floor (10m^2)	Lump Sum	5	500	2,500.00	257,500.00
Spiral heat exchanger	Lump sum	1	9,000	9,000.00	927,000.00
Re-injection well/disposal of brine	Lump sum	1	38,000	38,000.00	3,914,000.00
Medical Facilities	Lump sum	1	20,000	20,000.00	2,060,000.00
Sum Total				**221,228.00**	**22,786,484.00**
					-

Contingency		20%		44,245.60	4,557,296.80
Contractor cost: Sum Total				**265,473.60**	**27,343,780.80**
					-
Engineering Design		15%		39,821.04	4,101,567.12
Supervision		10%		26,547.36	2,734,378.08
Preparation cost		3%		7,964.21	820,313.42
					-
Grand Total				**339,806.21**	**35,000,039.63**