Proposal on the Use of Geothermal Brine for Space Cooling

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ABSTRACT

Kenya has a vast geothermal resource estimated to be more than 7000MWe, but currently only 209 MWe and 16 MWt are installed. The government of Kenya has mandated the Geothermal Development Company (GDC) to fast track the development of geothermal resources in the country. This includes availing 5000MWe worth of steam by the year 2030 for electricity generation and promoting direct uses.

In the past, the country has been using geothermal energy mainly for electricity generation but recently, with the creation of GDC, more emphasis is being put into direct uses. Among the various ways of utilizing geothermal heat directly, spacing cooling has been identified as one of the possible option in Kenya, especially in the northern parts of the rift valley where the climate is semi-arid.

The development of geothermal resources in these areas through drilling of geothermal wells is expected to yield substantial amount of brine with a large thermal potential which can be utilized in the running of space cooling appliances through absorption cooling.

The purpose of this paper is to assess the viability of using geothermal brine with absorption cooling systems for space cooling. An assessment in terms of technical viability and cost implications is carried out.

1.0. Introduction

The world is shifting its focus to the exploitation and use of indigenous and renewable energy resources which are environmental friendly. In Kenya, geothermal energy is one of these resources. Kenya's geothermal resource is found mainly in the rift valley which runs from north to south of the country. Fourteen high temperature geothermal prospects have been identified along the Kenya rift valley with a potential estimated to be more than 7000MWe (Simiyu, 2010). A large potential for direct use is also present. Other geothermal prospects have been identified at Mwananyamala in the coast province and Homa Hills in Nyanza province.

Direct utilization of geothermal energy has been practiced for centuries all over the world. Bathing and balneological uses are some of the oldest known ways but recently, more applications are emerging and experiencing some considerable growth. Geothermal energy can be used directly in many sectors such as industrial applications, domestic applications, agricultural and animal husbandry applications.

In Kenya, direct use of geothermal heat is not well developed. On a commercial scale, only Oserian farm in Naivasha uses geothermal heat for heating 50 hectares of greenhouse, soil fumigation and treatment of fertilized irrigation water. Greenhouse heating at the Oserian farm helps in controlling humidity and enhancing growth of the rose flowers. Other minor direct applications are in Eburru where the local community uses steam from two shallow wells to dry pyrethrum and vegetables and the condensate used as domestic water. At Lake Bogoria spa hotel, geothermally heated water from a nearby hot spring is used to heat a swimming pool.

The Geothermal Development Company has started its flagship geothermal project in Menengai prospect which is projected to be worth about 1250MWe (Omenda, 2010). Besides electricity generation, direct utilization is expected to form an important part of the project. Among the projects to be developed at Menengai and its environs include the drilling of geothermal wells, construction of power stations and development of direct utilization applications. The possibilities for direct utilization around Menengai are diverse and depend to a large extent on the economic activities in the area. Agriculture is widely practiced with maize and wheat being the chief crops cultivated. Dairy farming is also done extensively. A number of processing industries are found in Nakuru town and they present possibilities for direct uses. Tourism is a big business in Menengai and Nakuru due to the caldera and the national park which are the main attractions. Complementing tourism is a hospitality industry composed mainly of hotel facilities. These activities and facilities present opportunities for direct uses such as drying of grains, milk pasteurization, heating swimming pools, saunas and space cooling.

2.0. Space Cooling

The mandate of GDC entails among other things to support and promote development of direct uses of geothermal resources. Therefore, it behooves the company to be in the frontline in utilizing geothermal heat directly wherever and whenever applicable. One of the options being explored is space cooling for offices and cold rooms using hot geothermal brine with absorption cooling systems.

Kenya is a tropical country whose annual temperatures remain relatively constant throughout the year. Room temperatures range from around 23°C to 35°C in most parts of the country. The higher end of this temperature range is experienced mainly in the northern parts of the Kenya Rift Valley, from Lake Bogoria to Barrier geothermal prospects (Figure 1) which have a semi-arid climate.

Areas in other parts of the country such as Nakuru have a fair weather but during the hot season air conditioning is a necessity. This phenomenon necessitates the use of air conditioning

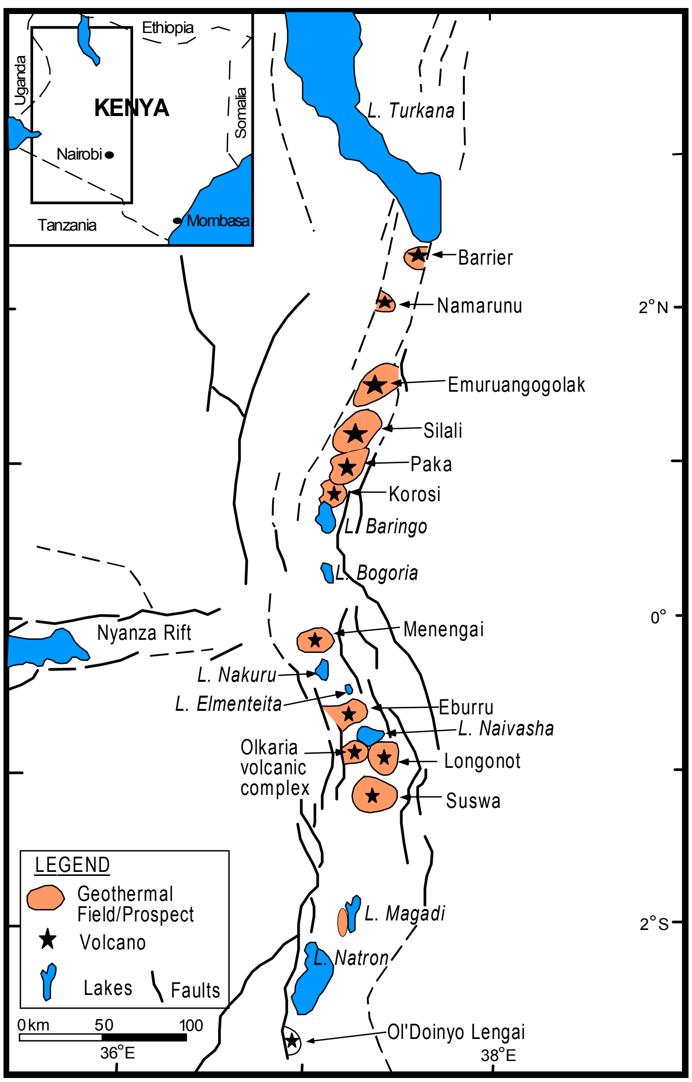

Figure 1. Geothermal prospects within the Kenyan Rift (Omenda, 2003).

in buildings to provide comfort to the occupants. The proximity of Nakuru town to the Menengai geothermal prospect provides a ready market for direct utilization of geothermal energy for air conditioning due to the presence of many commercial buildings.

The area around Menengai is endowed with a big agriculture potential. The horticultural industry is well established in the region and is mostly dominated by fruit and vegetable farming. To this effect, a large market place is situated in Nakuru town for the vendors to sell their produce. However, a proper storage facility for the surplus produce is lacking and losses due to spoilage of unsold produce are common. A high temperature geothermal resource so near to such a facility needs to be utilized as a source of energy for cold rooms for storage of these products, some of which can be stored for up to six months if kept at low temperatures of about 4°C, e.g. potatoes which retain their texture and undergo little sprouting (Taylor, undated). Dairy farming is another well-established industry in the area. Milk has a very short shelf life which necessitates immediate processing by pasteurization and later cold storage which can be achieved by the use of geothermally cooled cold rooms.

2.1. Absorption Cooling

Space cooling in Kenya is dominated by the compressor refrigerators which rely on electricity for their operation. Electricity in Kenya is however expensive and unreliable especially during the dry season. Furthermore, many parts of the country are without electricity supply.

Kenya's geothermal prospects are found mostly in rural areas where there are no electricity distribution lines. Others like Menengai are situated near towns which require a lot of cheap energy to drive their economies. The development of Menengai geothermal prospect will avail surplus thermal energy from spent brine which if tapped would drive cooling processes using absorption cooling.

2.2. Working Principle of an Absorption Cooler

An absorption cooling system is made up of an absorber, an evaporator, a generator, a condenser, heat exchanger and pumps. Two fluids, an absorber and a refrigerant circulate through the system to provide the required cooling. Hot brine is supplied to the generator section and its heat transferred to the absorbent/refrigerant solution. This heat causes the refrigerant to be boiled out of the solution in a distillation process. The refrigerant vapour that results passes into the condenser section where a cooling medium is used to condense the vapour back to a liquid state. The refrigerant then flows down to the evaporator section where it is sprayed over tubes containing the fluid to be cooled. By maintaining a very low pressure in the absorber-evaporator section, the refrigerant boils at a very low temperature. This boiling causes the refrigerant to absorb heat from the medium to be cooled, thus, lowering its temperature. Evaporated refrigerant then passes into the absorber section where it is mixed with an absorbent/refrigerant solution that is very low in refrigerant content. This solution tends to absorb the vapour from the evaporator section. This is the absorption process that gives the cycle its name. The solution is then pumped to the generator section to repeat the cycle (Figure 2).

Vapour absorption systems are of two types: Lithium Bromide/water cycle, where water is the refrigerant while lithium bromide is the absorbent. This configuration is used mainly for air condition-

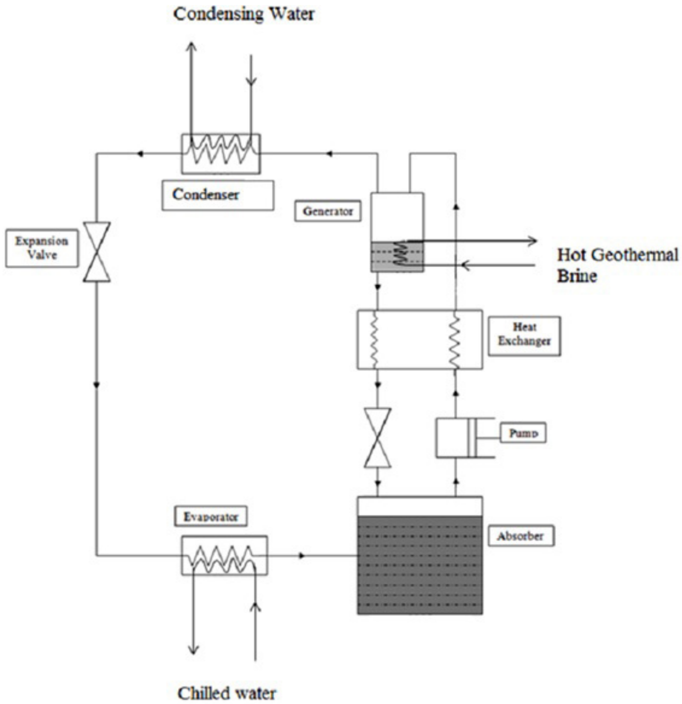

Figure 2. Schematic Diagram of an Absorption Cooling System.

ing where temperatures do not go below 0°C as this would result in freezing of the refrigerant. The second configuration is the water/ammonia cycle where ammonia is the refrigerant. This is mainly used for refrigeration since it achieves temperatures below 0°C.

Lithium Bromide/water cycle requires brine to be input at temperatures of at least 120°C while higher temperatures are necessary for water/ammonia cycle. This is necessary in order to achieve high efficiency with the systems because lower temperatures result in diminished cooling capacity. Addition of heat to the generator causes the absorbent/refrigerant mixture to boil at a fixed temperature since the pressure is fairly constant. Therefore, a reduction in the temperature of brine will result in a reduction in the temperature difference between the boiling mixture and the geothermal water. This in turn results in reduced heat transfer and reduced refrigeration capacity since both have a linear relationship.

2.3. Heat Source (Geothermal Brine)

Wells drilled in Menengai are expected to produce a large quantity of two phase geothermal fluids for electricity generation. Steam will be used for electricity generation while thermal energy present in the separated brine will be used for direct applications. Since the brine is from high enthalpy resource, it chemistry may pose utilization challenges such as corrosion due to low pH and deposition as a result of high silica levels (Ellis and Mahon, 1977).

The suitability of a geothermal fluid for any application depends on its enthalpy and chemistry. A fluid is classified as being low enthalpy (<90°C), medium enthalpy (90°C-150°C) or high enthalpy (>150°) depending on the nature of the geothermal system from which it originates (Muffler and Cataldi, 1978). Most direct uses utilize geothermal fluid from low - medium enthalpy resource while fluids from high enthalpy resource are suitable for electricity generation. However, the waste brine from a high enthalpy resource is ideal for use in absorption refrigeration applications.

The common practice at many geothermal power stations including OlKaria has been to re-inject hot brine back into the ground immediately after separation from the steam. This is an inefficient way of utilizing geothermal energy because the brine is usually at a high temperature. At such a temperature, the brine has a lot of thermal energy which can be utilized for other applications such as hot water supply, greenhouse heating or space cooling. It is clear that direct use is a way of diversifying utilization of geothermal resource.

The major problem associated with the use of brine is the presence of many dissolved solids such as silica, quartz and calcite. The solutes are usually in equilibrium with each other at high temperature and pressure in the reservoir. Upon change of temperature and pressure, deposition of amorphous silica on the pipeline and other equipment e.g. heat exchangers and valves normally occurs. To arrest silica deposition, heat exchange should be done at a temperature above the super saturation point of silica. Other factors such as pH and ion concentration also determine the rate of deposition. Therefore, pH reduction and dilution of the brine before utilization are options which can be used to inhibit

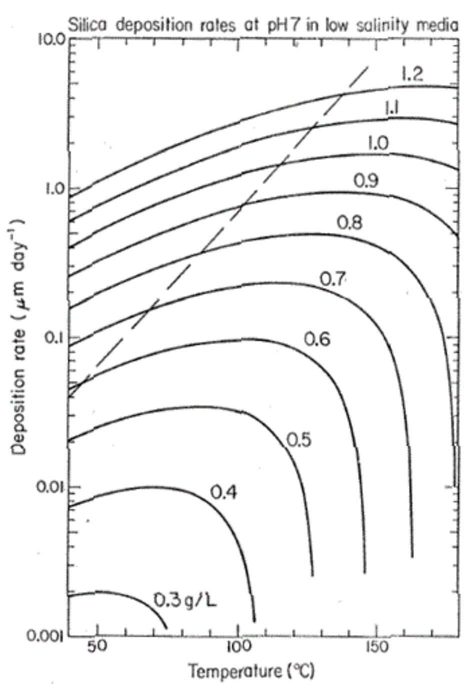

Figure 3. Rate of silica deposition at varying concentrations and pH = 7 (Kruger and Ramey, 1978).

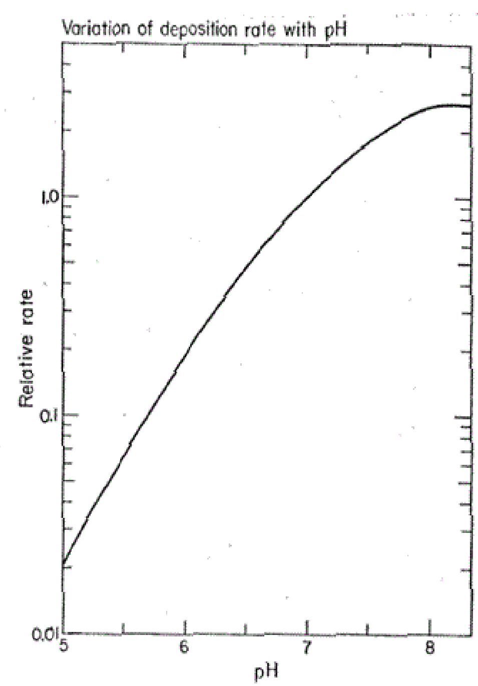

Figure 4. Rate of silica deposition at pH = x relative to rate of deposition at pH = 7, where x = 5, 6, 7, 8. (Kruger and Ramey, 1978).

deposition (Gudmundsson 1983). Figure 3 and Figure 4 show the effect of pH alteration on the deposition rate of amorphous silica. It is also desirable that the level of reactive gases such as CO_2, H_2S, H_2, CH_4 and N_2 should be low so that corrosion is kept to a minimum.

A reduction in pH from 7 to 6 results in an 80% decrease in the rate of deposition (Figure 4). At such a rate, the deposition is likely not to be a major concern. In addition, heat exchange can be done at a much lower temperature and this will result in more energy being availed for utilization.

3.0. Preliminary Design

Excess heat in building comes from external sources such as solar radiation, conduction through the walls and infiltration of the outside air. In addition, appliances, lighting and people in the building also emit heat and moisture which cause the humidity and temperature in the rooms to rise. The external and internal heats constitute the total cooling load which needs to be rejected from the building for the comfort of the occupants. A space cooling system is thus designed taking into account the area of the space to be cooled, environmental factors and the number of persons who occupy the space to be cooled.

The use into which a building is to be put is very important in determining the amount of cooling required. Assuming that cooling is to be provided for a learning institution, the cooling system should be designed such that it can cater for the cooling needs of lecture halls, dining hall, offices, dormitories and a library. Assuming a total of 27 students and 6 administrators are expected to use these facilities, the total space required to comfortably accommodate this number of people in the institution is 688m^2 of floor area (Table 1). In order to maintain a temperature of 24°C in the building, a system with a cooling capacity of 29 tons of refrigeration or 100 kW is required.

Table 1. Cooling design values.

Applications	Occupancy m^2/person		Lighting: w/m^2		Refrigeration w/m^2	
	Av.	High	Av.	High	Av.	High
Educational Facilities	2.3	1.9	21.6	43.2	189.2	252.2
Dormitories, Hotels, Motels	13.9	9.3	10.8	21.6	126.1	173.5
Libraries & Museums	5.6	3.7	10.8	16.2	135.6	189.2
Office Buildings	10.2	7.4	43.2	64.6	135.6	205
Private Offices	11.6	9.3	21.6	62.4	135.6	205
Restaurants:						
Large	1.4	1.2	16.2	18.3	378.3	205
Medium	1.4	1.2	16.2	18.3	315.4	378.3

The area of the floor in a building depends to a large extent on the number of people who are to occupy it as shown below (Figure 5).

Since this energy is to be extracted from geothermal brine, it is important to ensure that heat exchange is done at an appropriate temperature so that scaling does not become a problem. Assuming a brine outlet temperature of 112°C, Figure 6 shows the flow rate required at different pressure values in order to provide adequate cooling.

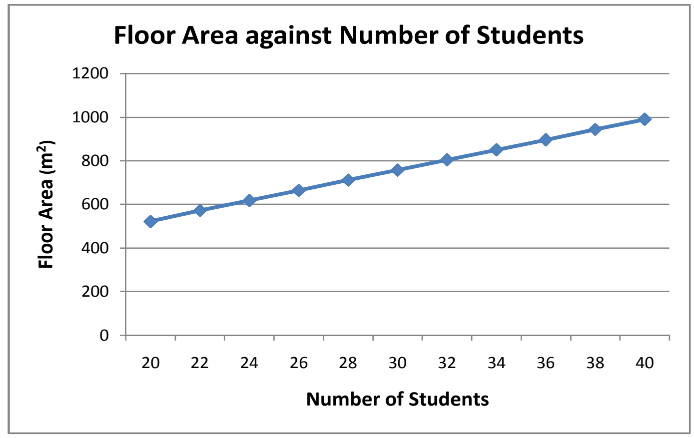

Figure 5. Variation of the floor area with the number of students.

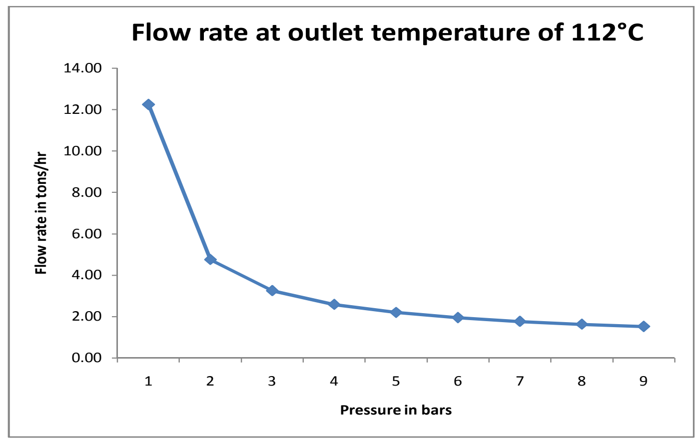

Figure 6. Flow rate at outlet temperature of 112°C.

The amount of thermal energy that can be extracted from brine depends to a large extent on the flow rate and the difference between the inlet and outlet temperatures. The bigger the difference between the two temperatures, the more the energy that can be extracted at any given flow rate. This is illustrated in Figure 7 shows below.

The inlet temperature of the brine is dependent on the pressure of the brine. Brine at a high pressure is at a higher temperature than brine at a low pressure as shown in Figure 8.

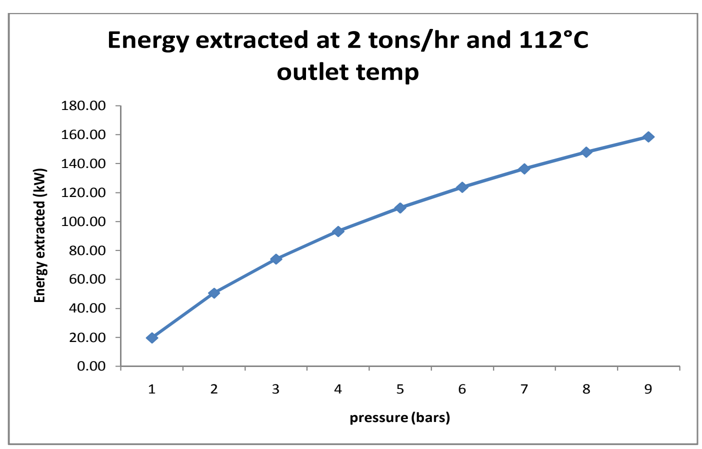

Figure 7. Energy extracted at 2 tons/hr. and 112°C outlet temp.

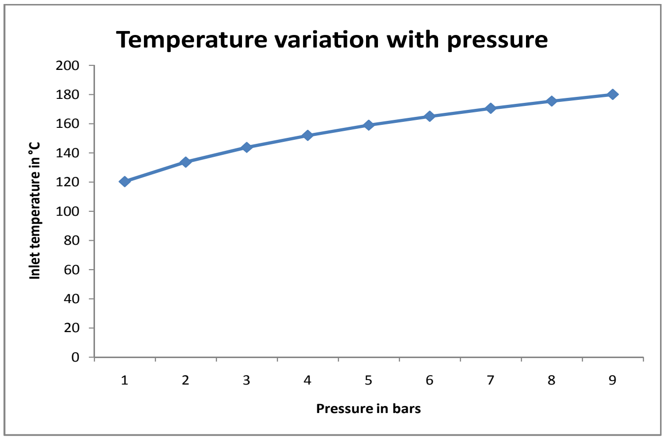

Figure 8. Effect of pressure on temperature.

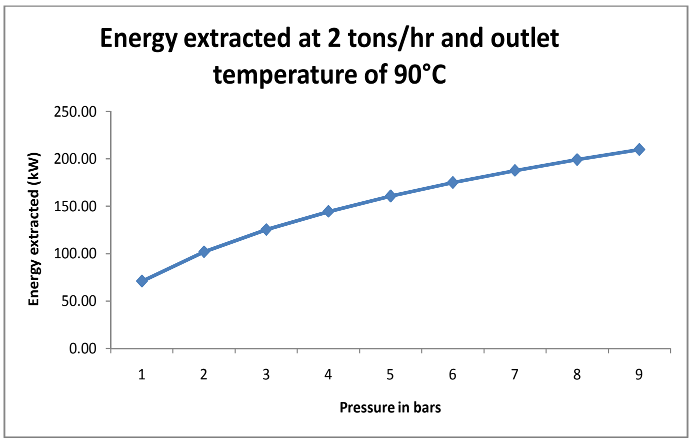

Figure 9. Energy extracted at 2 tons/hr. and outlet temperature of 90°C.

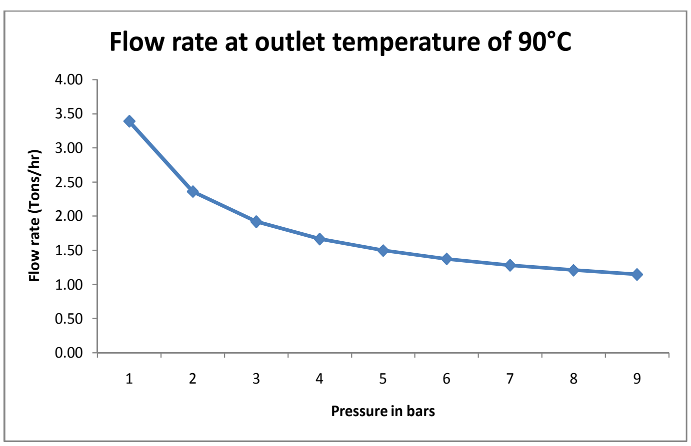

Figure 10. Flow rate at outlet temperature of 90°C.

For brine at any given temperature, a reduction in pH results in a significant reduction in the rate of deposition. From Figure 3, assume that the pH is reduced to 6 for the brine with a silica concentration of 7g/L. At 112°C the rate of deposition will drop to 0.04μm/day from 0.2μm/day. This allows for heat exchange to be carried out at a much lower temperature. If now heat exchange is done at 90°C the following energy can be extracted from the brine as shown in Figure 9. At the same conditions, the flow rate of the brine is lower than that of untreated brine since more energy can now be extracted. Figure10 shows this scenario.

4.0. Costing

Cost is a very important aspect and should be put into consideration before any project is implemented. For most projects, costs are of two types: installation costs and operating/running costs. The installation costs can be assumed to be fixed while operating costs are variable and depends on several factors such as maintenance, power consumption and labor.

For an absorption cooling system, installation cost increases with increase in cooling capacity. It consists of the cost of absorption chiller and condenser equipment as shown in Figure.11. The plot shows the installed costs for the absorption chillers and auxiliary condenser equipment (cooling tower, cooling water pumps and cooling water piping) used in absorption cooling.

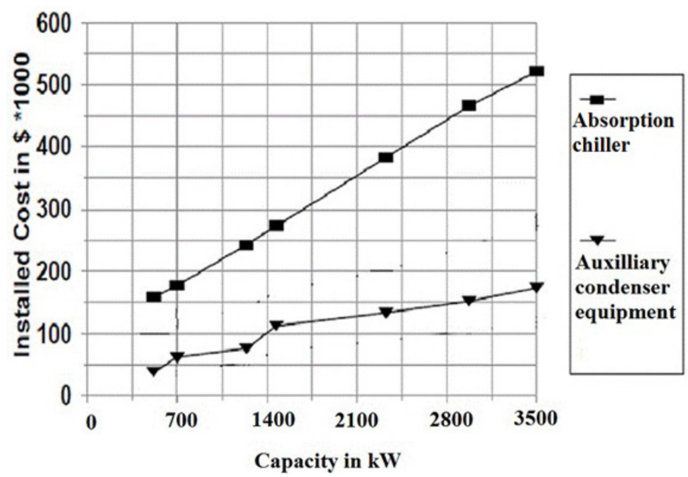

Figure 11. Chiller and auxiliary equipment costs (Means, 1996).

From the graph above the cost of installing an absorption cooling system is estimated to be around US $165/kW of cooling load. This is done by summing up the gradients of the two curves to obtain the cost per unit power. This value does not however include the cost of air distribution system and pipeline for transporting brine.

5.0. Conclusion

Space cooling in offices for comfort of the occupants and development of cold rooms for storage of agricultural produce in Menengai area and other regions in the Rift Valley is very important. Absorption cooling has been considered to this effect in terms of technology requirements and cost implications. The absorption cooling system is favored greatly by the expected surplus heat from geothermal brine and the relatively low cost of installation.

The exploitation and development of Menengai geothermal prospect by GDC will result in the availability of a lot of energy laden brine. Prior planning is required to determine how best to use this energy before the brine is re-injected in order to enhance efficiency in the utilization of the geothermal resource. Direct utilization is one of the most appropriate ways of enhancing efficiency in the use of geothermal resources.

It is however important to note that the use of brine for any direct application will depend to a large extent on its chemistry and enthalpy. These properties can be determined with certainty only after drilling, laboratory analysis of the fluids and energy content determination.

The proximity of the point of utilization of brine to its point of origin should be reasonable in order to overcome some of the challenges associated with transportation. Long distances will lead to the following:

i. High cost due to the need for more piping material, controls and bigger pumps.
ii. Significant pressure and heat losses.
iii. Deposition of dissolved solids in the pipeline.

Lagging the pipeline with a good insulating material keeps heat losses to a minimum. A large volume of flow and a high flow rate also mitigate against heat loss. The surest way of countering the problem of deposition is use of heat exchangers at the point of re-injection to transfer heat from the brine to fresh water which is then piped to the utilization plant.

With an installation cost of less than US $200/kW of cooling load, absorption cooling systems are an attractive option for space cooling. Besides air conditioning for offices and cold storage rooms, they can also be applied in refrigeration, for which a demand exists in the dairy industry. By developing these applications, GDC will be meeting its mandate of supporting and promoting development of direct uses of geothermal resources.

6.0. Recommendations

a) Carry out further studies on the cost-benefits analysis of absorption cooling systems to determine their viability.
b) Install at least one absorption cooling system in the country (Nakuru) to determine the technical and economic effects of the technology.
c) For commercial viability of absorption cooling systems, the installation cost needs to be subsidized for affordability.

7.0. References

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APPENDIX

1. Load Calculations

The table below gives the design values for various elements of total heat load calculations. For preliminary design, the refrigeration estimate values in column 4 of Table 1 are sufficient but for thorough design, the formulas below can be applied.

Table 1. Cooling design values.

Applications	Occupancy m2/person		Lighting: w/m2		Refrigeration w/m2.	
	Av.	High	Av.	High	Av.	High
Apartments (Flats)	9.3	4.6	10.8	21.6	94.6	110.4
Auditoriums, Theatres	0.9	0.5	10.8	21.6	151.3	378.3
Educational Facilities *(E.g. Schools, Colleges, Universities, etc.*	2.3	1.9	21.6	43.2	189.2	252.2
Factories :						
Assembly Areas	3.2	2.3	32.4	48.2	157.6	252.2
Light Manufacturing	13.9	9.3	97.2	107.6	189.2	252.2
Hospitals :						
Patient Rooms	4.6	2.3	10.8	16.2	173.5	236.5
Public Areas	80	4.6	10.8	16.2	271.2	346.9
Hotels, Motels						
Dormitories	13.9	9.3	10.8	21.6	126.1	173.5
Libraries & Museums	5.6	3.7	10.8	16.2	135.6	189.2
Office Buildings	10.2	7.4	43.2	64.6	135.6	205
Private Offices	11.6	9.3	21.6	62.4	135.6	205
Typing Department	7.9	6.5	53.8	80.7	135.6	205
Restaurants:						
Large	1.4	1.2	16.2	18.3	378.3	205
Medium	1.4	1.2	16.2	18.3	315.4	378.3

RMY/Heat Load Calculation edited 11/7/2009.

2. Design Conditions

The values in the table above are based on the design parameter shown in Table 2.

Table 2. Comfort Design parameters.

	Dry bulb (°C)	Wet bulb (°C)	% RH	Go/Lb.
Outside	33 (day) 25 (night)	27 (day) 24 (night)	60 (day) 95 (night)	138
Room	24	18	55	72

3. Formulas

area = number of people*space per person 1)

refrigeration load = load per unit area*area 2)

brine thermal energy = refrigeration load/efficiency 3)

refrigeration load = mass flow rate*specific heat capacity of water*change in temperature between inlet and outlet temperatures 4)