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Burundi Geothermal Energy Production Project

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ABSTRACT

Burundi is a country located within the Eastern African Great Rift Valley. This zone has increased temperature gradients and natural heat stream. Geothermal power plants operating within this geological formation in Kenya and Ethiopia bring about positive results. The results of geological recognition of Burundi area are presented in view of geothermal energy production. With the historical studies made from 1969 to 1982, a description of 15 hot springs, 14 geothermal locations and chemical analysis have been reported. In the Rusizi rift valley, the source temperature rising through the porous sediments at the surface of Ruhwa spring recorded 68 °C. Quartz geo-thermometer application suggested an underground source temperature around 110-120 °C. Discharges arising from sediments were carbon dioxide rich, which confirms the presence of a powerful heat source. An exploitable geothermal source whose temperature lies in the range of 100-160 °C, may exist in the Rusizi valley. Therefore, an anomalously geothermal gradient may be expected in this region. In this aim, a geophysical and drilling exploration project is planned by IRCED company (International Research Center in Engineering for Development) and the ELC-Electroconsult S.p.A of Italy, in order to produce an exploitable geothermal energy.

1. INTRODUCTION

The geothermal data of Burundi are recognized from reconnaissance field trip. Recent reconnaissance mission has been made in 1982 by two scientists from the National Energy Authority of Iceland. The conclusion of the survey revealed that there is considerable volcanism around Lake Kivu in house vicinity geothermal heat has been reported. The chemical composition of the Lake water is affected by the geothermal heat. The Northwestern part of Burundi is on the edge of the volcanic region of the Lake Kivu. From the geological point of view, this is the most promising geothermal resource. The recent visit of the students of Lycée Rumonge with their teacher of Geography to Mugara hot spring (photos on figure 1) revealed that the flow of hot water could be enough to turn a power plant. There remain the exploration studies to confirm the possibility of electricity generation.

Figure 1: Photos of visit of student of Lycée Rumonge at Mugara hot spring.

2. GEOLOGY AND GEOTHERMAL CONTEXT IN AFRICA AND BURUNDI

2.1. Geological context

The structure of the African continent is characterized by a set of extensive basins and domes of increasing altitude to the East (figure 2) which culminate in the East African plateau region. This continental form could have played the role of an insulator compared to the mantle heat flux which resulted in warming of the mantle. It is therefore reasonable to think that large African basins and domes would be formed by mantle convection, which had to be intensified under African continent because of the heat trapped under the plate (Hirsch and Roussel 2009) The East Africa Rift System (EARS) is an active intra-continental rift system, comprising an axial rift. The EARS is a unique succession of tectonic basins (rift valleys, grabens) linked by intra-continental transforms and segmented by transfer zones and accommodation zones (Hardarson 2016, Chorowicz 2005). On the surface, the main tectonic features are normal faults but there are also strike-slip faults, oblique-slip faults and reverse faults. The rift system may be divided into two main branches, i.e. the eastern branch and the western branch. The western branch runs over 2,100 km, from Lake Albert in the north to lake Malawi in the south (Chorowicz 2005).

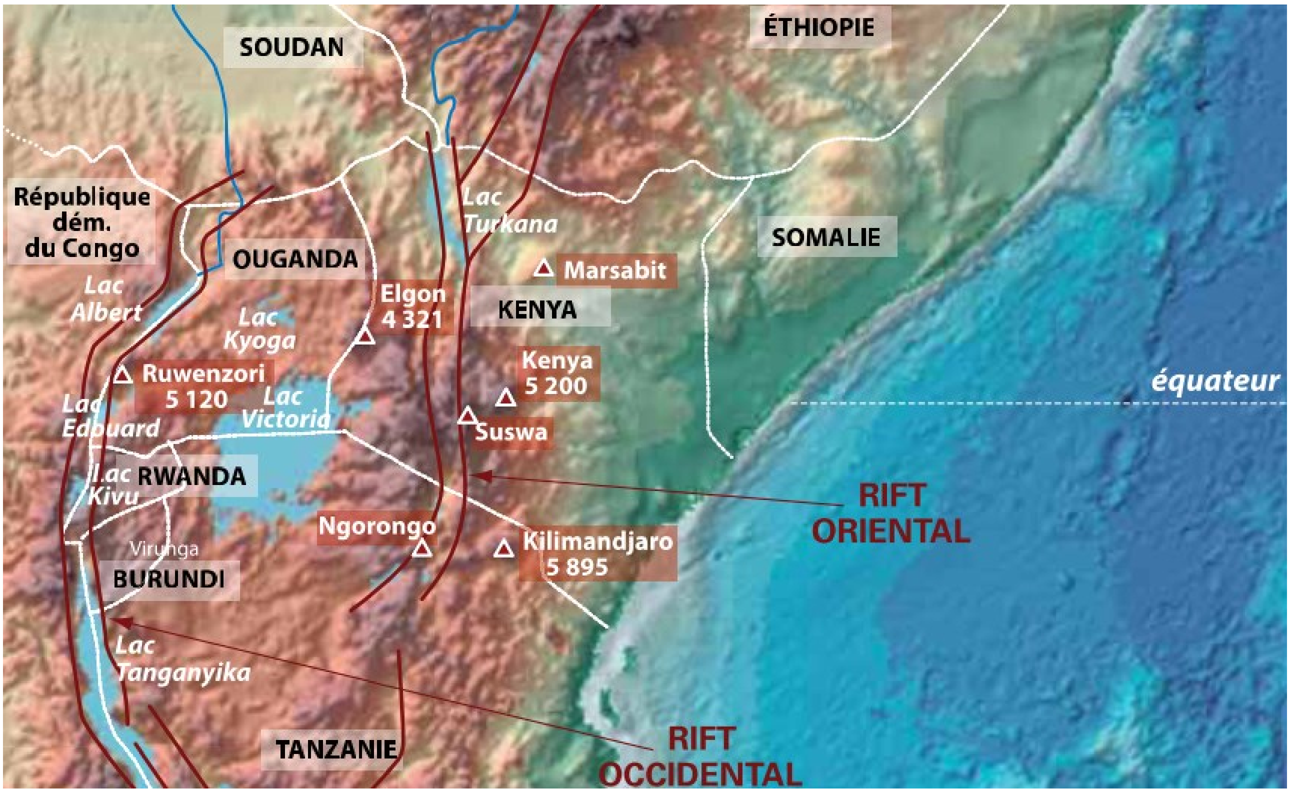

Figure 2: Map of African Rift System (Hirsch and Roussel 2009)

Burundian bedrock is mostly composed of Precambrian formations and complexes. Dominant rock types are quartzite, gneiss, granite, dolomite, schist, sandstones and conglomerate. The Rusizi valley is filled with thick sequences of alluvium formed during the Holocene. Sediments from Pleistocene, mostly lithified sandstone and conglomerates, are characteristic of the area east of the Rusizi valley, overlying Precambrian formation. A strip of Tertiary tholeiitic and alkali lavas is found in North West Burundi (Covering some 30 km2) originating from the volcanic zone of Sud-Kivu in Rwanda. The hot spring within the rift valley emerges from sediments except for the springs at Mugara where water rises from Precambrian quartzites. Hot springs located outside the Rift Valley all emerge from Precambrian rocks. The hot springs in North West Burundi, e.g Ruhwa, Ruhanga and Cibitoke do not seem to be directly associated with the Cenozoic basalts found in that area but several researches have inferred that underplating of magma might be an important process beneath the Tanganyika Rift (figure 3)

Figure 3: Geothermal sites in Burundi (Wakana 2013)

2.2. Geothermal context

East Africa is one of the few regions in the word with Iceland, where telluric mechanisms affecting the planet cause the Earth's mantle (at a temperature of 1300 °C) to rise to shallow depth due to the dynamic plates. This extension phenomenon results in a heat flux that can be up to ten times higher than the terrestrial average: it can reach about 1 MW per Km^2. As a result, temperatures of 250° C can be reached at 1500 or 2000 m depth. As a result, a renewable electricity can be produced by drilling using steam directly sent in turbine. East Africa is from the edge of the Red Sea to the South of the continent characterized by high altitudes constituting high plateaus themselves dotted with peak summits. These include the volcanic origin (Mount Kenya, Kilimanjaro, etc…) who are cut by deep valleys, delimited by faults and dotted with lakes, where we know that active volcanoes, thermal springs and fumaroles. All those geographical features result from the same telluric phenomenon. Over the past 25 million years, the whole feature has been affected by a rise in the Earth's mantle, which first bulged the crust before fracturing and breaking it, separating the Somalian plate from its Nubian root and allowing the release on the surface the magma. This rise of warm mantle (1300°C) is accompanied by a lowering of pressure which causes a partial melting of the minerals that constitute it and the production of basaltic magma rising to the surface through the open faults of the rift. This axial meridian bulge results in fact from the phenomenon of extension affecting the earth's crust in a roughly perpendicular direction which continues to be active today (Varet 2014).

2.3. Chemical context

Chemical geo-thermometers suggest the highest source temperatures in the Rusizi Rift Valley rising through the porous sediments (Ruhwa spring records 68°C, at surface). Quartz geo-thermometer application suggests an underground source temperature around 110°-120° C. All discharges arising from sediments were carbon dioxide rich, indicating the presence of a powerful heat source. The high carbon dioxide concentrations observed in analyses, lead to super saturation with respect to calcium carbonate in some cases. Therefore, care would have to be exercised in order to avoid calcium carbonate deposition during exploitation. In summary an exploitable geothermal source whose temperature lies in the range of 100°-160°C, may exist in the Rusizi valley and probably extend well into RDC and Rwanda. This source is thought to be connected to the volcanic area south of Lake Kivu. Therefore, an anomalously geothermal gradient may be expected in this region (Wakana 2013 , Nizeye 2012).

2.4. Temperature of groundwater

The groundwater temperature measurement made in the vicinity of Rumonge near Mugara hot spring using loggers installed in the piezometers of three boreholes and those indicated by the analyses made with the continuous flow cell in the piezometers allowed to estimate a geothermal gradient in the order of 5.07°C per 100m depth. This value is very high than the global norm, which is in the order of 2.5 to 3 °C per 100m depth (Tiberghien et al. 2015). This global geothermal gradient corresponds to a thermal energy flow of about 60mW/m2, which allow to estimate the thermal energy flow of the studied area of 101.4mW/m2. This value of the energy flow and those of the groundwater temperature given in table 1 show the potential of production of thermal energy in the region.

Table 1: Groundwater temperature in the vicinity of Mugara, Rumonge (Tiberghien et al. 2015)

Piezometer	Average temperature in continuous flow	Average temperature while sampling	Temperature of logger
1	29,68	29,00	26,1
2		25,70	24,5
3		26,25	
4	25,50	26,35	24,8
5	28,50	28,20	

3. POSSIBILITY OF GEOTHERMAL ELECTRICITY PRODUCTION IN BURUNDI

3.1. Geothermal Power Plant

There are several types of power plants basically divided into two groups: steam cycles and binary cycles. The most economic generation of electricity from high temperature geothermal resources is generally achieved from conventional steam turbine plants (single or double flash cycle system), unless some specific exploitation restrictions (Caixia 2008). In the steam cycle the geothermal fluid can boil or “flash” above boiling point by lowering the pressure, then becoming a two-phase fluid, and the steam is separated from the brine and expanded in a turbine. The process of lowering the pressure to boil the fluid is called “flash process” (Geirdal 2013, Geirdal et al.2013). Flash cycle is the simplest and conventional form and most geothermal wells produce two phase fluids, consisting of brine and steam. The main difference between a binary power plant and a steam cycle plant is that in the binary cycle, the geothermal fluid does not come in contact with the turbine, that is done by using a working fluid which is heated by the geothermal fluid through a heat exchanger in a closed cycle by means of a feed pump, the geothermal fluid is returned after the heat exchanger (Geirdal 2013).

The binary cycles use a secondary working fluid in a closed cycle. A heat exchanger is used to transfer heat from the geothermal fluid to the working fluid, the working fluid is vaporized and expanded in a turbine, and the cooled geothermal fluid is re-injected to the reservoir. Generally, there are two main types of binary cycles, the Organic Rankin Cycle (ORC) and the Kalina Cycle. The ORC commonly

uses hydrocarbons as the appropriate working fluid and Kalina uses a water-ammonium mixture as a working fluid (Kopuničová 2009). Beside the Flash steam and binary power plant, there are combinations of cycles like:

- combined cycle or hybrid plants;

- combined heat and power based on geothermal energy.

According to the existing data in Burundi, the binary power plant which use the moderate temperature and low temperatures (85-170°C) of geothermal resources is suitable.

3.2. Binary power plant investigation in Burundi

Binary system has two cycles: the first is the heat exchanger cycle of geothermal fluid where the working fluid absorbs heat from the geothermal fluid via the heat exchanger and the second is the ORC working cycle or Kalina cycle. These two cycles are separated, so only the heat transfer takes place through the heat exchangers (Caixia 2008).

By selecting the appropriate working fluid, the ORC system (fig. 4) can be designed to operate with inlet temperature in the range 85-170°C. The upper temperature limit is restricted by the thermal stability of the organic binary fluids (working fluid). The lower temperature limit is primarily restricted by practical and economic considerations, as the required heat exchanger size for a given capacity becomes impractical.

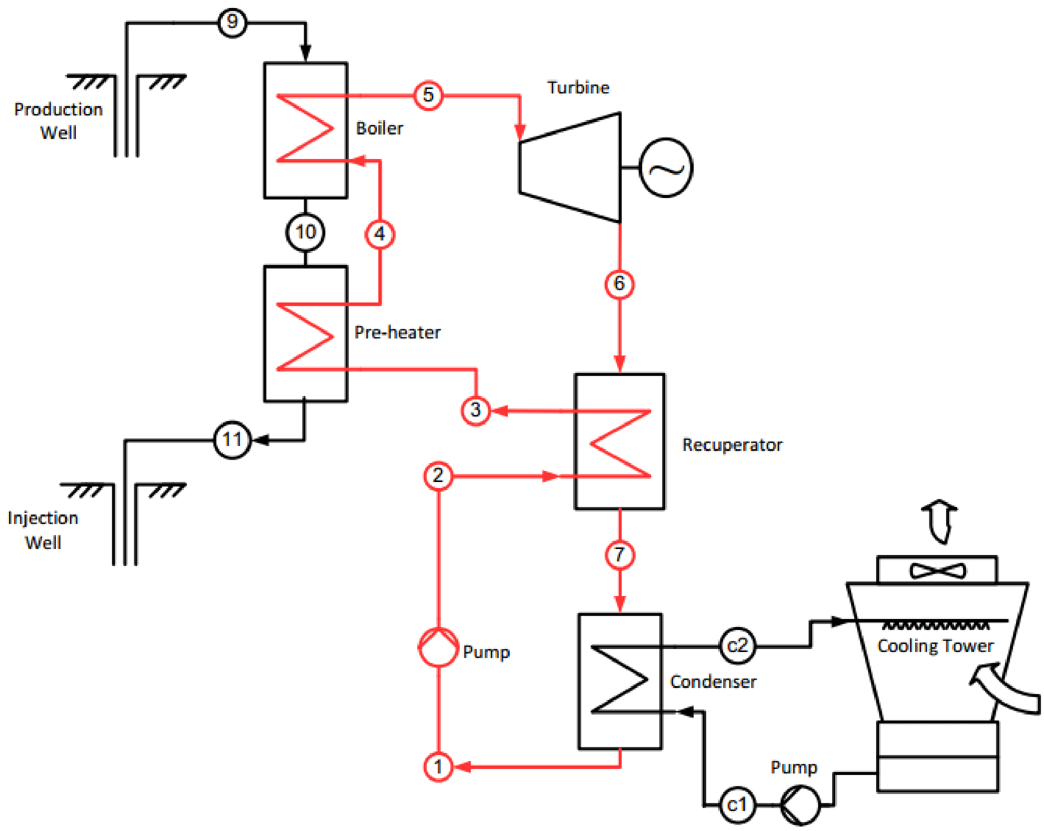

Figure 4: ORC diagram (Salas 2012)

According to the experiences, generally, isobutane gives more power output compared with isopentane (Salas 2012). Thus, the working fluid is selected both from the optimizing power output view and requirement of the critical temperatures. The small fraction of the geothermal fluid, which is a saturated steam, is expanded in the turbine. There, the steam energy is transformed into mechanical energy in the shaft. It is assumed that the entropy is constant (isentropic) from the inlet at station 5 to the ideal exit point 6. The isentropic enthalpy at 6 is then calculated from the pressure at point 6 and the entropy at point 5. The expiation is irreversible, and the steam entropy is higher. Turbines are classified with an isentropic efficiency parameter that is given by the manufacturer.

The geothermal fluid enters the boiler at the source inlet temperature at station 9 and, if the pressure is kept sufficiently high, any non-condensable gases will be released from the liquid; therefore, a gas extraction system is not required. The geothermal fluid is then cooled down in the boiler and heater and sent to re-injection at station 11. The regeneration process serves only to move the highest power production towards a higher geothermal return temperature; regeneration can help in the case of a lower limit on the geothermal fluid temperature imposed by chemistry or by the requirements of a secondary process. For the binary condenser, the superheated vapor must be cooled previous to condensation. Therefore, the process has to be divided into two steps. First, cooling the superheated vapor, second, condensation of the working fluid vapor.

A Kalina cycle (fig. 5) is a modification of traditional binary ORC system using a mixture of ammonia and water as the working fluid instead of a pure working fluid. The basic ammonia-water steam is vaporized in the evaporator and then separated into a saturated rich vapor ammonia-water mixture steam and a saturated liquid ammonia-water mixture stream in the separator. The main benefit of Kalina cycle is that heat addition to the process happens at a variable temperature, and can thus be fitted to the falling temperature of a heat source with a finite heat capacity, reducing the generation of entropy in the heat exchange with the primary fluid.

The goal of the Kalina cycle is that by using a mixture of ammonia and water as the working fluid, the temperature profile of the working fluid will more closely follow the temperature profile of the heat source or sink (Jones 2011). The efficiency of Kalian cycle system is found by varying pressure and fraction of ammonia in water. The calculation concerned all range of temperature between 90 to 140°C in order to find the optimum operation. The same procedure was used to calculate the net power output for different pressure and fraction of ammonia.

The result shows ammonia water as a working fluid which can be used at different pressure by changing the concentration of ammonia mixture as working fluid in different pressure and different ration of ammonia in the mixture. The Kalina cycle achieves at thermodynamic efficiency (brine effectiveness) that is approximately 50% greater than that of standard binary Rankin plants(Dickson and Fanelli 2003).

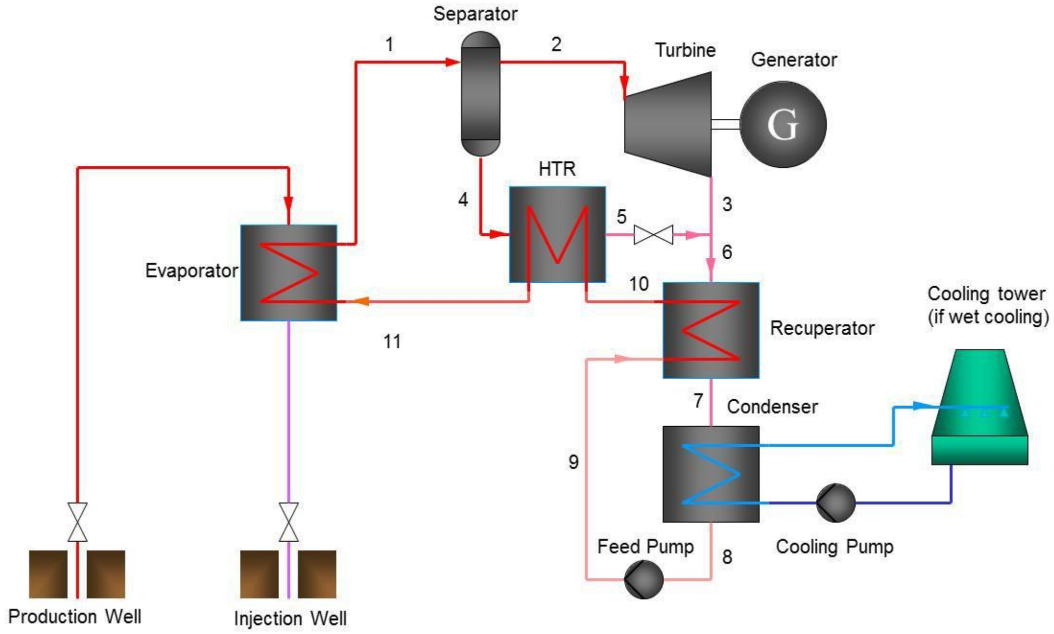

Figure 5: Kalina dagram (GEOELEC 2012)

3.3. Power plant performance analysis

In his study, Wakana (2013) developed the thermodynamic parameters analyses of the binary model cycle and an Engineering Equation Solver (EES) software has been used to estimate the parameter values of the model. Having pressure of turbine inlet, temperature of geothermal resource, ambient temperature, reinjection temperature and condenser temperature, other parameters could be calculated by EES. The calculation has been done with a geothermal mass flow input of 1 kg.s -1 as source of heat. The reinjection temperature used in the study was fixed at 70°C. For the geothermal source with the temperatures between 110 and 160°C, it is difficult to use rejection temperatures lower than 70-80°C, the condenser temperature was fixed at 45° C because the ambient temperature is very high with an average of 30° C. The Kalina cycle can be appreciated for its thermodynamic properties. Its working fluid is a mixture that has variable boiling temperature that allows it to decrease or increase the power output without changes in equipment components. But it is expensive compared to ORC because it requires a large area for the condenser and evaporator. For temperatures higher than 140°C, the Kalina cycle might give a better performance than ORC with regard to the first and second laws of thermodynamics. Economic analysis showed the feasibility of a binary power plant of low temperature in Rusizi Valley in Burundi. However, the working fluid must be well selected to reach the economic goal. In his study, isopentane was shown to be economical if used for such low temperature. The maximum power output at 140°C and a geofluid mass flow rate of 80 kg/s could reach 4.9 MW, and a minimum at the same temperature with a mass flow rate of 20 kg/s is around 1.2 MW, using isopentane as the working fluid. At 90°C, the maximum power output that could be reached is 1MW with a mass flow of 80 kg/s, and a minimum 0.3 MW with a mass flow rate of 20 kg/s (Wakana 2013).

4.EXPLORATION PLAN

The Geothermal Exploration which IRCED plan to make in Burundi will be mainly based on 6 stages. In parallel, IRCED will continue to search for funds to allow power plant to start.

Stage 1: Reconnaissance-Gathering of existing data;

Stage 2: Exploration;

Stage 3: Exploration drilling;

Stage 4: Prefeasibility studies;

Stage 5: Further drilling wells;

Stage 6: Feasibility studies.

All those stages will be subjected to an external review by a geothermal expert panel in order to enhance the quality of the exploration work undertaken as well as the validity of the results.

Following to positive exploration result at stage 2, other activities related to drilling exploration will start such as: environmental and social impact assessment, drilling permit preparation and searching for funds.

In Burundi, the status of geothermal development is at reconnaissance stage (ICEIDA 2012). The detailed activities of different stages which IRCED plan to make are as follow:

4.1. Reconnaissance study

The geothermal field in Burundi is considered as a greenfield fairly open and accessible with low to intermediate temperature. The exploration land will cover 100 Km^2. Reconnaissance studies will entail desktop study of previous exploration work, reviewing all existing data and recognizing where data are lacking. The desktop study will be followed by a visit of two or three geothermal experts to the site to collect additional existing data and maps, meet with local authorities and local geo-scientists and engineers who may have studied the field. The visit will also include some sampling and analyses of geothermal water and/or steam, preliminary mapping, temperature and flow measurements. The visit will primarily evaluate the potential market for the geothermal energy.

4.2. Exploration

Exploration will be based on geological, geochemical, geophysical studies and scientific report delivering.

The geological studies will be organized into three main groups as well as:

1.Geothermal mapping/structural mapping, including remote sensing techniques. Those activities will be made by geothermal specialist (geologist/structural geologist, hydrogeologist and geochemists). The aim will be mapping out of the main structures and geological units, connecting the geothermal surface manifestations to the underlying structures/stratigraphy. The preliminary hydrogeological map will be delivered.

2.Collect samples for analyses (geothermometers, age determination, petrophysics analyses, etc…) and temperature measurements of surface manifestations.

3.Soil temperature mapping will be carried out. Soil temperature is used to locate up flow zones and active faults (ICEIDA 2012).

The geochemical studies will be organized into two main groups such as:

1.Chemical sampling, analyses and interpretation of fluids from the geothermal spring and estimation of subsurface temperatures using conventional geothermometers and estimation of potential chemical gas problems during drilling, flow testing and power production. The preliminary hydro-geochemical model of the source will be developed at this step.

2.Gas emission measurements, CO2/Radon. Diffuse degassing measurements will be used to locate active faults.

The geophysical studies will be based on four main studies as well as:

1.Surface geophysical methods for subsurface resistivity measurements (TEM and MT) for outlining geothermal anomaly and define up and out flow zones and determine potential heat sources.

2.Gravity surveying, this is to map out any gravity anomaly that might be linked to the geothermal resource. This may include a micro-gravity study.

3.Magnetic mapping which is used in the low temperature exploration to map dykes and faults in bedrock

4.Micro-seismic monitoring (passive seismic) will be used to recognize magmatic bodies at depts and to control structures of the reservoirs and map out active fractures and fracture zones (epicenters of very small earthquakes) likely to be permeable. Seismometers could be installed to monitor the area in question for few months to collect seismic data.

4.3 Drilling Exploration

Drilling in geothermal exploration typically begin long time before construction of power plant. Four main drilling well are organized such as:

4.3.1. Thermal gradient holes

Drilling of thermal gradient holes (TGH) is an important step prior to drilling a production well. Drilling of TGH may even precede some geophysical surveys. The TGH are shallow, narrow and can be drilled quickly using a trick-mounted rig. The TGH measure the gradient, i.e the change in temperature with the depth. A higher gradient indicates a greater temperature anomaly. There are two main purpose of drilling of a TGH:

First, to assess whether deeper temperatures in the geothermal reservoir will be hot enough to support commercial production

Second, a series of TGH should help to delineate a thermal anomaly and define the extend of the source

In drilling of a TGH, first shallow holes are drilled to depths of 500 to 1000 feet. Once shallow holes have been completed, the holes of 1000 to 4000 feet can be drilled to penetrate the geothermal reservoir. If the last step is successfully completed, it will provide a wealthy information regarding the geothermal resource. The depth to which a TGH can be drilled depend often on the geologic and hydraulic conditions.

4.3.2. Core drilling

Core drilling or slims-hole drilling is a method which uses a drill bit with a shallow center to extract cylinder, or cores of rock. Core drilling is sometimes used in the drilling of production wells as well as the well is drilled to greater depths to allow analyses of the recovered cores in order to better understand subsurface geology and locate fractures within a resource.

4.3.3. Production well

Drilling of production well represents the transitional step of the exploration and the construction phase of developing of the geothermal resource. The construction phase is initiated once a production well is deemed successful. For this reason, a significant emphasis is placed upon improving exploration technologies in order to improve drilling success rate.

4.3.4. Injection well

In order to complete the confirmation of geothermal project, injection wells must be drilled in order to return hot water from the production zone to the geothermal aquifer. A geothermal resource cannot be fully confirmed until this process is completed to demonstrate that an underground system can provide hot water to the power plant sustainably over time.

4.4. Exploration cost prevision

According to Geothermal compact program (ICEIDA 2012), the cost of reconnaissance stage in each country of East Africa is planned to be 100 000 USD, the exploration stage is planned to 1 000 000 USD. Additional cost related to administration, exploration license and other are planned to cost 3 000 000 USD. The cost of other stages is estimated with uncertainty and the global cost of the geothermal exploration is planned to be 13 000 000 USD. The most common cost for drilling a 2500m well with an 8-1/2″ production zone and directly drilled with 30° angle is $7 million. This cost can be as low as under $4million in Iceland, Romania and Turkey and up $15million in Japan. If incident occur, cost can easily escalate and several recent cases in Iceland, New Zealand and East Africa have resulted in cost exceeding $15million. The main reason for this difference is the number of days for drilling and rig mobilization, ranging from 45 on average in Iceland to over 100 days in East Africa. Other reasons include differences in environmental requirements, geological formation etc. The total cost of exploration in East Africa and essentially in Burundi is estimated to be $28 million.

5.CONCLUSION

The available data of an exploitable geothermal source whose temperature lies in the range of 100 to 160 °C reveals that a geothermal power plant could be constructed in Burundi using Kalina cycle system and making a choice of isopentane as a working fluid. The power output could be in the range of 0.3 MW to 4.9 MW. This power output is calculated based on the reconnaissance field trip. If a geothermal exploration is made, the result could conclude to an increased geothermal source. In this purpose, IRCED plan to make a geothermal exploration to confirm the electricity generation of different geothermal sources in Burundi.

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