Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Directions of Energy Balance Improvement in Burundi in the Aspect of Geothermal Energy Resources

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Keywords: Burundi, borehole heat exchangers (BHE), geothermal source heat pumps (GSHP), electricity balance

ABSTRACT

Burundi is a country located within the Eastern African Great Rift Valley. This zone has increased temperature gradients and natural heat stream of Earth. Geothermal power plants operate within this geological formation in Kenya and Ethiopia. They bring about positive results therefore are being still developed. The results of geological recognition of Burundi area are presented in view of geothermal energy production for electricity generation. The Burundi energy balance is presented. Large amounts of energy are imported from the Democratic Republic of Congo. The directions of electrical energy use and sources of its production are described. Simultaneously, in a number of cases, electricity is used for heating (tap water) and cooling purposes (e.g. in Bujumbura hotels). Part of the used electrical energy could be saved in Burundi if heat pumps were applied. The paper presents an analysis of work conditions of heat pumps with borehole heat exchangers for heating/cooling purposes in a given hotel. The analysis shows mathematically evaluated prognosis of the use of BHE systems for cooling and heating. There are presented energy and economic conditions of use the system in the capital city Bujumbura.

1. INTRODUCTION

Burundi is one of the five countries of the East African Community (EAC), Burundi, Kenya, Rwanda, Uganda and Tanzania. With 27,834 km^2, his population is about 8.863 millions (2010). Situated in the Great Lakes and Western brunch of the Eastern Great Rift Valley region, he is bordered by Republic Democratic of Congo (RDC) at his West, Rwanda at his North and Tanzania in the East and South.

Burundi has multiple opportunities in the energy sector as well as:
- hydroelectric energy with an untapped commercial potential of 414 MW (Atlas, 2013);
- potential for the development of solar energy and wind energy on the edge of Lake Tanganyika;
- possible commercial geothermal power production not exploited yet;
- there are also many other sites for hydroelectric power generation.

In fact, few of those potentialities are exploited as well as:
- eight hydroelectric power plants with a total installed capacity of 32.81 MW;
- the thermal power plant of 10 MW.

The total electricity production in 2012 is 245.97 GWh. The import of electricity is 42.4% compared to the total production (16.3 MW from Ruzizi I &II in RDC). The system peak was reached 47.76 MWh (28.06.2012 at 20 h in the evening). The Peak demand currently stands at 51.7 MW. This demand of 51.7 MW peak is small compared to the actual demand, in fact, a lot of unmet needs due to lack of energy reserves available. Therefore, the network has a deficit of 8.74 MW during the day and a deficit between 12 and 23 MW during peak hours.·

Burundi hosts also a great potential of raw minerals such as Nickel, Gold, Tantalum, Tungsten, Tin, Rare Earth Element, and Phosphate. All of that huge resource cannot be extracted because of a lack of sufficient energy.

Improvement of energy balance can be made in Burundi in other to solve that challenge. Two ways are developed in this work:
- geothermal power plant;
- saving energy used in some hostels in Bujumbura by using heat pump systems for heating tap water and air-conditioning.

2. GEOLOGY CONTEXT OF GEOTHERMAL ACTIVITY IN BURUNDI

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 (Chrorowicz, 2005).

On the surface, the main tectonic features are normal faults but there are also strike-slip faults, oblique-slipe 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 a distance of 2,100 km, from Lake Albert in the north to Lake Malawi in the south.

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. Sedments 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 NW Burundi (Covering some 30 km^2) originating from the volcanic zone of Sud-Kivu in Rwanda.

The hot spring within the rift valley emerges from sediments with the exception of the springs at Mugara where the water rises from Precambrian quartzites. Hot springs located outside the Rift Valley all emerge from Precambrian rocks. The hot springs in NW 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 (e.g. Kampunzu et al. 1998, fig. 1)

Figure 1: Geothermal sites in Burundi (Friorickson et al. 2012)

3. ENERGY CONDITIONS IN BURUNDI

Burundi's energy sector as a whole is characterized by the predominance of consumption of biomass in the form of wood and charcoal. The modern forms of energy from hydropower or renewable energies are poorly represented in the energy balance. Indeed, the energy balance of Burundi presents the consumption of various forms of energy in the following estimated amounts:

- wood and charcoal: 96.6%;

- power electricity: 0.6%;

- petroleum products 2.7%;

- other: 0.1%.

This is mainly due to the following reasons:

- difficulties in mobilizing funds for investment in hydroelectric (main source of energy operated);

- high cost of drawing lines and connecting individuals to the national grid;

- insufficient income households and rural communities to connect to the national grid or for the purchase of equipment for renewable energy;

- outdated of equipment and limited resources of REGIDESO to meet the growing demand for electric power.

Faced with this situation, the Government has adopted an energy policy and its Sector Strategy and its Action Plan in 2013 based on the following fundamental objectives:

- provide sufficient energy and quality services required for industrial, economic and social activities;

- increase the number of people with access to modern forms of energy;

- meeting basic energy needs while ensuring the preservation of the environment meet the growing demand for electric power.

For to achieve these objectives, several development partners including the World Bank, the European Union, UNDP, are providing the Technical Assistance to the Ministry of Energy and Mines, in the overall review of the legal framework and regulation to make it more efficient and less burdensome for private investors.

The Peak demand currently stands at 51.7 MW. This demand peak is small compared to the actual demand, in fact, a lot of unmet needs due to lack of energy reserves available.

4. Geothermal electricity conditions in the Eastern African Great Rift Valley

The East African Rift Valley is one of the major tectonic structures of the earth where the heat energy of the interior of the earth escapes to the surface. The East African Rift valley extends for about 6,500 km from the Middle East (Dead Sea-Jordan Valley) in the North to Mozambique in the south (fig. 2). The estimated geothermal energy resource potential in the East African Rift Valley is more than 20 GW.

Despite the high geothermal potential of the East African Rift Valley, only Kenya and Ethiopia have installed a capacity of about 220 MW. Some countries are at various exploration stages. So far, other countries such as Burundi, DRC, Malawi, Zambia, and Mozambique have not gone beyond the exploration (Zemekun 2012).

Geothermal resources manifestations exist in many locations at the western part of Burundi. This western part of Burundi is connecting with East Africa Rift System in western branch (fig. 2).

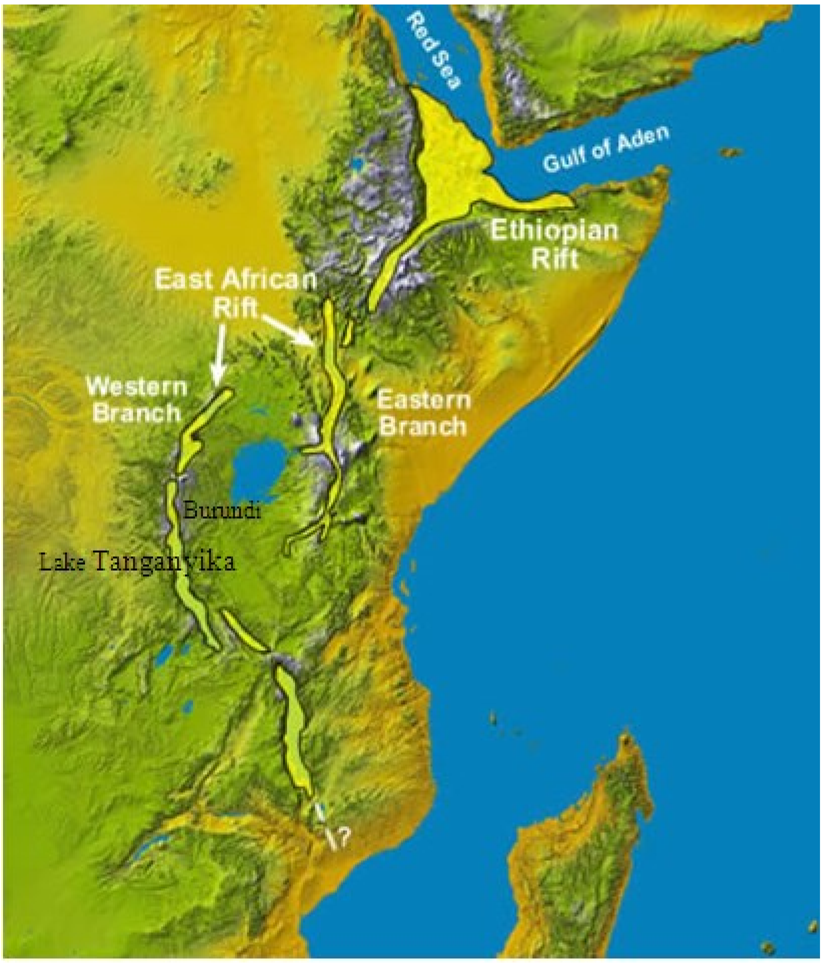

Figure 2: Map of the African Great Rift Valley (Modified from Wood and Grith 2014)

4.1. Possibility of geothermal electricity production in Kenya

According to the International Geothermal Association, Kenya will become the world leader if the planned projects are completed on time. The country set an ambitious target of producing 5 GW by 2030, which will power millions of homes: all energy generated is fed into the national grid to increase the percentage of households served. The hydroelectric energy generators can run at as 58% at their installed capacity.

Geothermal, however, consistently delivers almost full capacity. About 13% of Kenya’s power generating capacity is geothermal, but in real terms it contributes 22% to the grid. That is one of the reasons why the expansion is based on geothermal (Hatcher 2013).

4.2. Possibility of geothermal electricity production in Tanzania

Still unexploited, Tanzania has an expected 650 MW geothermal potential ready to harvest. One of the largest reserves lies in the Ngozi-Songwe geothermal system. Geothermal Power Tanzanian Ltd. has received regulatory approval in Tanzania to proceed with exploration drilling.

Holding several prospecting licence in Mbeya region, GPT is ready to develop the geothermal reservoir in the Ngozi volcanic complex. Prior to drilling deep geothermal wells, an environmental study had to be undertaken to provide that all national regulations were satisfied regarding safety, reliability and quality.

GPT has achieved this mile stone, which allows the company to advance to the deep drilling stage and advance the project towards realizing Tanzania's first geothermal project, being an estimated 100 MW of power. GPT set an innovative hand mark for the development of geothermal energy in Tanzania (Lxrichter 2013).

4.3. Possibility of geothermal electricity production in Ethiopia

Ethiopia is among the few countries in Africa with a significant amount of geothermal resources. These resources are found scattered in the Main Ethiopia Rift and in the Afar depression that covers an area of 150,000 km^2. Based on the results of the investigations, Ethiopia could possibly generate more than 5 GW of electric power from geothermal resources alone.

A new era of resource utilization started in 1998 by installing the 7.2 MW net capacity pilot power plant at Aluto-Langano. Initially, there was a disruption in power generation due to technical problems. These were studied and are currently being rectified (Geological Survey of Ethiopia 2014).

Till now, Ethiopia has signed a preliminary agreement with a US-Icelandic firm for a $4 billion private sector investment intended to tap its vast geothermal power resources and help it become a major exporter of energy for East Africa. Reykjavik Geothermal, whose Icelandic geothermal expertise is backed by US investors, signed a deal with Ethiopia to construct a 1 GW geothermal power plat, Africa's largest, in the volcanically active Rift valley. When complete, the project will be Ethiopia's biggest foreign direct investment, run by its first privately owned utility (Maacho 2013).

4.4. Possibility of geothermal electricity production in Burundi

Burundi belongs to the western branch of the Rift Valley in Africa where the Ruhwa and Mahoro geothermal sources were pinpointed (Nizeye 2012). Several synthesis of dispersed data from literature exist (Nizeye 2013), describing sources in East Congo (Rollet 1957), in Tanzania (James 1967), in East Africa, around Lake Kivu (Boutakaff 1933), in Burundi (Nitt1969).

Deestra and al. (1969) and other local unpublished authors have made inventory and description of principal hot springs in Burundi. They confirmed available data and pointed out geothermal events along African Great Rift in a particular geo-structural context, with geochemical consideration.

These historical studies (1969 to 1982) covered in Burundi eight geothermal locations. A description of 15 hot springs, 14 geothermal locations and chemical analysis from 13 of them has been reported. The surrounding's geology was described and the geological analysis of the discharges has been recommended.

In the Rusizi rift valley, the source temperature rising through the porous sediments (Ruhwa spring record 68°C at surface). Quartz geo-thermometer application suggests underground source temperature around 110-120°C (Fridriksson et al. 2012). He notes that all discharges arising from sediments were carbon dioxide rich, indicating the presence of a powerful heat source.

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 DRC 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 (Nizeye 2012).

5. HOTELS AND THEIR ENERGY CONSUMPTION IN BUJUMBURA

Hotels in Burundi use much energy in heating tap water, and cooling room. Some of this energy can be saved using heat pumps and borehole heat exchangers systems. In this point, was calculate the energy used in a typical hotel in Bujumbura town, which can be saved.

Bujumbura has 16 main classified hotels as: King's Conference Centre, Hotel Botanika, Roca Golf Hotel, Hotel la Palmeraie, Hotel Dolce Vita Resort, Hotel club du Lac Tanganyika, Hotel Restaurent Vaya, Hotel Residence Ubuntu, Nonara Beach Resort, Royal Palace Hotel, Ego Hotel, Yombe Palace Hotel, Residence "Snt Rose", Le clos des Limba, Water Front hotel Cercle Nautique. Some pictures of them are on fig. 3. From the left, King's Conference Centre: classified 1st, in the middle, Botanika hotel classified 2nd, and and at the right Roca golf Hotel classified 3rd.

Figure 3: Photos of tree main classfied hotels in Bujumbura

The electrical energy consumption in a typical hotel in Bujumbura city for heat/cold production is about 400 kWh if all machines are working. Usual working time for cooling mode is 8 hours and 5 hours for water heating. What gives loads per day as:

- 3.2 MWh for air conditioning

- 2 MWh for hot water production.

In total, this represents a significant percentage of the total electricity production in Burundi.

6. DIRECTIONS OF ENERGY BALANCE IMPROVEMENT IN BURUNDI

Improvement of energy balance in Burundi consists in releasing his energy production. Beside hydroelectric power, geothermal energy can be developed in two ways:

- geothermal power plant;

- geothermal heat pumps systems for saving energy by heating tape water and cooling rooms in some hotels in Burundi.

6.1. 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 is allowed to 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).

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 (Kompunicova 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.

6.2. 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.

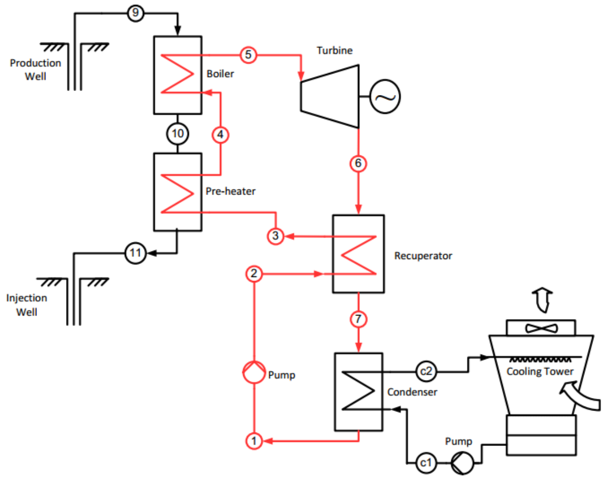

Figure 4: ORC diagramme (Salas 2012)

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 table below shows the critical temperature and pressure of some main working fluid applying in ORC which must fit the geothermal fluid heat source.

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.

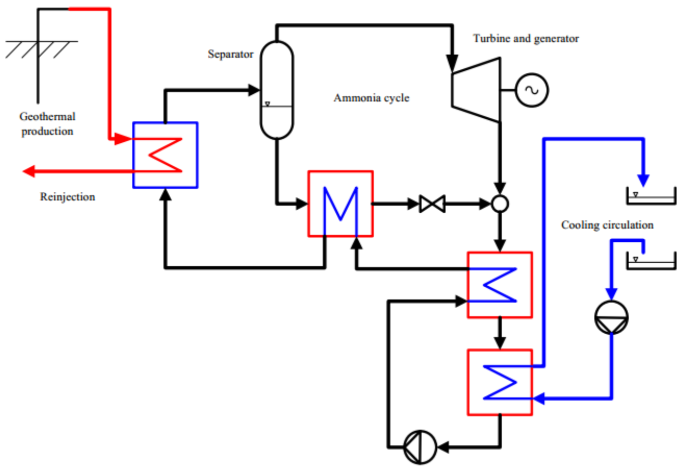

Figure 5: Kalina cycle diagramme (Caixia 2008)

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).

6.3. Power plant performance analysis

In the study (Wakana 2013), the thermodynamic parameters of the binary model cycle were developed and Engineering Equation Solver (EES) software used to estimate the parameters values of model binary cycle. Having pressure of turbine inlet, temperature of geothermal resource, ambient temperature, reinjection temperature and condenser temperature, other parameters could be calculated by EES helpful. The calculation was done with a geothermal mass flow input of 1 $kg\cdot s^{-1}$ as source of heat. The reinjection temperature used in the study was fixed at 70°C considering the low enthalpy of the geothermal resource according to the reconnaissance study report of geothermal resource in the Rusizi valley in Burundi (Wakana 2013) . For the geothermal field that have temperatures between 110 and 160°C, it is difficult to use rejection temperatures lower than 70-80°C, the latter temperature is a crucial parameter in plant design (Franco and Villani 2009). The condenser temperature was fixed at 45°C because the ambient temperature is very high with average of 30°C. The analyses results of binary power plant model for all working fluid choose are presented by Wakana (2013).

7. SAVING ENERGY BY USING HEAT PUMPS SYSTEM

A geothermal heat pump or ground source heat pump (GSHP) is a central heating and/or cooling system that pumps heat to or from the ground. Generally it uses the earth as a heat source (in the winter) or a heat sink (in the summer).This design takes advantage of the moderate temperature in the ground to boost efficiency and reduce the operational cost of heating and cooling systems, and may be combined with solar heating to form a geosolar system with even greater efficiency.

They are also known by other names, including geoexchange, earth-coupled, earth energy systems. The engineering and scientific communities prefer the terms “geoexchange” or “ground source heat pumps” to avoid confusion with traditional geothermal power, which uses high temperature heat source to generate electricity (Rafferty and Kevin 1997).

Depending on latitude, the temperature beneath the upper 6 m (20 ft) of earth’s surface maintains a nearly constant temperature between 10 and 16°C (50 and 60°F), if the temperature is undisturbed by the presence of a heat pump. Like a refrigerator or air conditioner, these systems use a heat pump to force the transfer of heat from the ground.

Heat pumps can transfer heat from a cool space to a warn space, against the natural direction of flow, or they can enhance the natural flow of heat from a warn area to a cool one.

7.1. Climatic conditions in Burundi

Burundi in general has a tropical high land climate, with a considerable daily temperature range in many areas. Temperature also varies considerably from one region to another, caused by the differences in altitude. The central plateau enjoys pleasantly cool weather, with an average temperature of 20°C (68°F). The area around Lake Tanganyika is warmer, average 23°C (73°F), the highest mountain areas are cooler, average 16°C (60°F).

Bujumbura’s average annual temperature is 23°C (73°F). Rain is irregular, falling most heavily in the northwest. Dry seasons vary in length, and there are sometimes long periods of drought.

However, four seasons can be distinguished: the long dry season (June- August), the short wet season (September-November), the short dry season (December- January), and the long Wet season (February-May). Most of Burundi receivers between 130 and 160 cm of rainfall a year. The Ruzizi plain and the northeast receive between 75 and 100 cm.

The average temperature is given by AEMET from 1997-2000 in table 1. The annually average temperature is 24.2°C and the thermal amplitude is 1.6°C.

Table 1: Average temperature of Burundi 1997-2000.

Month	J	F	MR	AL	M	JN	JL	AU	S	O	N	D
Max. T, °C	29.10	29.70	29.30	29.20	29.90	29.90	29.20	30	30.90	30.10	29.10	28.90
Min. T, °C	19.20	19.30	19.30	19.60	19.10	17.60	17.20	17.40	18.60	19.10	19.10	19.10
Average T, °C	24.15	24.50	24.30	24.40	24.50	23.75	23.20	23.70	24.75	24.60	24.10	24.00

Geothermal gradient in Burundi is higher than 60°C·km^{-1} (Pitman 2010) and natural earth heat flux in Burundi is 72 $mW\cdot m^{-2}$.

The lithologic profile data have been provided by the exploration results of Amoco Burundi Petroleum Company near the Lake Tanganyika. Profile to the 200 m shows table 2.

Table 2: Lithological profile and thermal rock properties.

Top, m	Bottom, m	Thickness, m	Lithology, minerals	Heat conductivity, $W \cdot m^{-1} \cdot K^{-1}$	Specific heat, $MJ \cdot m^{-3} \cdot K^{-1}$
0	50	50	micaceous, sand	2.0; 2.0 → 2.00	2.0; 2.2 → 2.10
50	100	50	quartz, feldspars, micas (muscovite)	6.0; 1.7; 2.0 → 3.23	2.1; 1.8; 2.2 → 2.03
100	150	50	micas	2.00	2.20
150	200	50	quartz, micas	6.0; 2.0 → 4.00	2.1; 2.2 → 2.15
			Average values to the depth of 100 m	2.62	2.07
			Average values to the depth of 200 m	2.81	2.12

7.2. Calculation of BHE exploitation

There is many possibilities to modelling borehole heat exchangers (BHEs) fields exploitation as underground thermal energy storages (UTES). Some of them is intended for energy output calculations in one BHE. There are also models for multi BHEs systems describes for example by Eskilsson (1987), Gonet et al. (2011).

In the presented investigations Earth Energy Designer software (EED3.16) were used. Same assumptions was made. There are:

- BHE depth: 200 m;

- distance between BHEs: 10 m, rectangular configuration;

- water in temperature 20°C as the heat carried fluid;

- flow rate of heat carrier: 20 $dm^3 \cdot min^{-1}$

- single U-pipe constructions of BHE, 40 mm outer pipe diameter, 3.7 mm wall thickness, PE as material of pipes;

- diameter of borehole: 143 mm;

- grout thermal conductivity: 1.8 $W \cdot m^{-1} \cdot K^{-1}$;

- shank spacing of U-pipe: 60 mm;

- COP in heating mode: 3.5, COP in cooling mode 2.5;

- heat demand for tap water: 42.84 $MWh \cdot month^{-1}$, cooling load 134.4 $MWh \cdot month^{-1}$ (according to the data in paragraph 5);

- minimum temperature of heat carrier in heating mode: 30,89°C, maximum by cooling 31,03°C (according to air temperature as in table 1),

- temperature difference of heat carrier in heat pump evaporator: 4 °C;

- average natural temperature in BHE to 200 m is (2·24.2°C+0.06·190)/2=29.9°C;

- time of operation: 20 years.

Results of calculations for BHEs with the borehole of 200 m depth are given as graphs below. Figure 6 is showing variation of water temperature in BHE during last year of exploatation. On fig. 7 changing values of temperature are presented in each year of operation. To keep the temperature conditions 625 BHEs was analysed. Unfortunately with this no. of BHEs as it is shown on fig. 6 and 7 and due to dates about climatic conditions in Burundi (Tab.1) it is not possible to achieve.

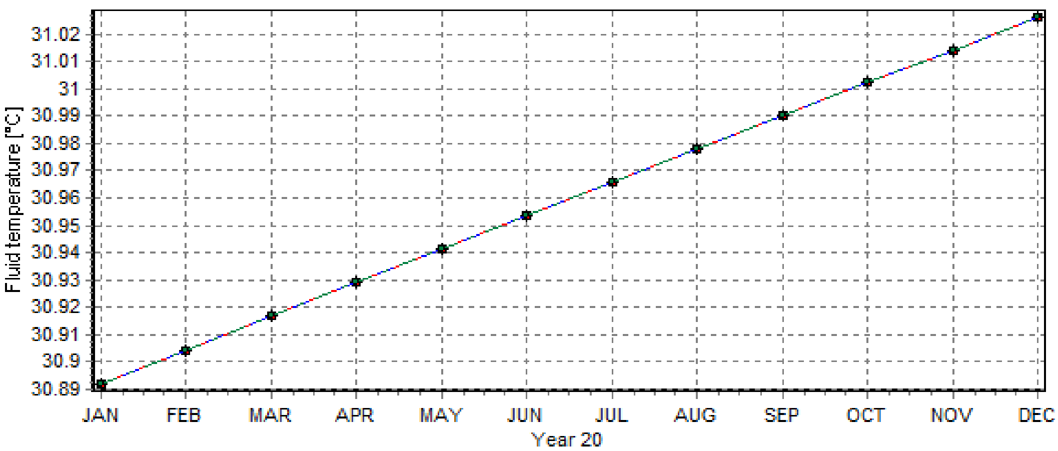

Figure 6: Fluid temperature in BHEs system in 20th year of operation

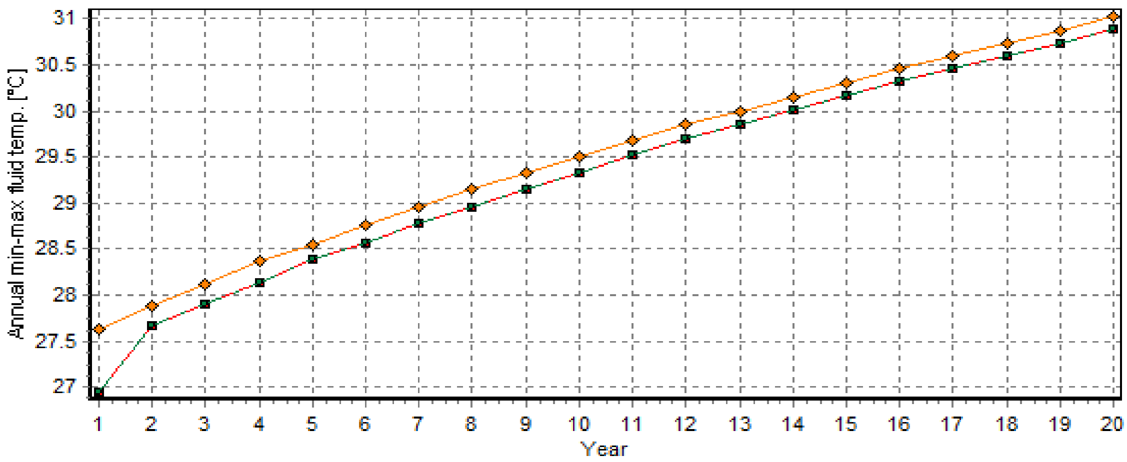

Figure 7: Fluid temperature in BHEs system during 20 year of operation

Because average power for heating tap water is 83,3 kW and cooling 133,3 kW for typical hotel other solutions can be more interesting. Active tap water heated with heat pump, and only partially cool. The second part of the heat discharged to the atmosphere (or cool with water from Lake Tanganyika). The surface temperature of the lake reaches 24-29°C, usually 26°C. Best solution for heating and cooling is use air heat pumps.

8. CONCLUSIONS

In spite of his great potential in energy resources, Burundi still has a lack of electricity. There are many untapped sites for hydroelectric power generation. For a global potential of 414 MW (Atlas 2013), only 32.81 MW are harvested (about 7.9 %).

Potential commercial geothermal power production is not exploited yet.

Solar energy and wind energy near the Lake Tanganyika can provide a great grid of power plant, but solar energy is a little bit exploited.

If all those energy resources are harvested, they could enable mining industry and a social development in Burundi.

All feasibility studies are finished on nickel and REE, but they remain unexploited because of the big challenge of energy power. Other explorations are still going on for gold, tantalum, tungsten, tin, and phosphate.

In the task of improving the energy balance in Burundi, there are huge geothermal possibilities to use.

Beside a geothermal power plant, energy can be saved in some hotels in Bujumbura or other cities by using heat pump systems instead for heating tap water and cooling rooms. Because of just constant air temperature during the year the best solution (also because of costs) for heating and cooling is use air heat pumps.

Exploration can be planned in other to get the exactly temperature of the area. That challenge can also be solved by enhanced geothermal methods.

9. REFERENCES

Caixia S.: Feasibility study of geothermal utilization of Yangbajain field in Tibet autonomous region, P.R.China, *United Nations University Geothermal Training Programme Reports*, **3** (2008) 76.

Dickson M.H., and Fanelli M.: *Geothermal Energy. Utilization and technology*. UNESCO, Renewable Energy Series, (2003) 205.

Franco, A., and Villani, M.,2009: Optimal design of binary cycle power plants for water-dominated, medium temperature geothermal fields. *Geothermics, 38-4*, 379-391.

Geirdal C.A.C.: Economic Comparison between a Well-head Geothermal Power Plant and a Traditional Geothermal Power Plant, Reykjavik University, *MSc Thesis* (2013) 100.

Geological Survey of Ethiopia web page (www.gse.gov.et) – 12 Dec 2013.

Hatcher J.: Kenya's energy revolution: full steam ahead for geothermal power, (2013), available in: http://www.theguardian.com/global-development/poverty-matters/2013/nov/22/kenya-geothermal-power-energy-revolution

James, T.C.: Thermal springs in Tanzania. *Transactions Applied Earth Science*, **76** (1967), B1-B18.

Jones D.A.: A study of the Kalina cycle system 11 for the recovery of industrial waste heat with heat pump augmentation. Auburn University, *MSc thesis*, (2011) 93.

Kampunzu A.B., Bonhomme M.G., and Kanika M.: Geochronology of volcanic rocks and evolution of the Cainozoic Western Branch of the East African Rift System. *Journal of African Earth Sciences,* **26** (1998) 441-461.

Kopunicova M.: Feasibility study of binary geothermal power plants in Eastern Slovakia: Analysis of ORC and Kalina power plants, RES - the School for Renewable Energy Science in affiliation with University of Iceland & the University of Akureyri, *MSc thesis*, (2009) 71.

Lxrichter: Geothermal Power Tanzania Ltd. receives permit for exploration drilling at Ngozi, (2013).

Maacho: Ethiopia to get $4 billion investment for leaps into geothermal power, Addis Abeba (2013).

Mac Nitt J.R.: Report of the United Nations Technical Assistance Mission on Geothermal Resources in Burundi, unpublished, (1969).

Mutima and Li: Au, Sn, W and Nb/Ta Mineralisation in Northern and Northeastern Burundi, University of Geosciences, Hongsham District, 388 Lumo Road, Hubei, Whuhan, 430074, China, (2010) 65.

Nizeye G.: Current Status of Geothermal Exploration in Burundi: Contribution to Regional Energy Needs in Central Africa, *Geothermal Risk Mitigation Facility – GRMF*, (2013) 124-126.

Pitman: Bulding an Exploaration Port Folio in central Africa Sure stream Petroleum (2010).

Potvin: NE Burundi-Gold Rich District London, December 2012 (2012).

Rafferty and Kevin: An information survival kit for the Prospective Residential Geothermal Heat Pump, Geo-Heat Centre, Quaterly bulletin 18(2) Klamath Falls, Oregon, Oregon Institute of Technology) (1997) 1-11.

Rollet A.: Centrale géothermique de Kiabukwa, Académie Royale Sciences Coloniales, **3/6** (1957), 1246-1262.

Songore: Matongo phosphate deposit in Burundi Fertilizer researcher, Kluwer Academic Publisher Printed in the Nethlands, Department of Geology and Mines, Ministry of Mines and Geology **30** (1991) 151-153.

Wood and Grith: East African's Great Rift Valley: A complex rift system, Michigan Technological University (2014).

Zemedkun: Overview of Geothermal Resource Exploration and Development in the East African Rift System, United Nations University Geothermal Training Programme, (2012) 10.