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Geothermal Energy: Power Potential of Hot Water from Oil Wells in Niger Delta, Nigeria

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***Abstract*—The need for generation of low cost constant electricity cannot be over emphasized. Due to the epileptic power supply in the Niger Delta in particular and Nigeria in general, it has become necessary to explore other sources of electricity which lead to cheap production costs and higher income. The geological and geophysical structure of the Niger Delta influences geothermal exploration within the province. The sedimentary basin of the Niger Delta region have been explored for oil and gas resources for decades, with large subsurface temperature data collected. On the basis of the subsurface temperature, particularly the Bottom Hole Temperature (BHT), data from oil wells in the Niger Delta, it has been found that geothermal gradient in the Niger Delta ranges from 1.3°C to 5.5°C/100m. Applying geothermal technology to produce electric power during oil production is a technology that could potentially decrease the amount spent on generators and power station in the Niger Delta region of Nigeria. This study focuses on the potential of geothermal energy to power oil field production equipment and light up host communities by producing commercial electric power. Many wells in the Niger Delta produce hydrocarbons as well as hot water. These wells which in general produce fluids with temperatures below 300F have been estimated of capable of generating as much as 5000MW of electric power.**

Keywords — Geothermal Energy, Electric Power, Geothermal gradients, Hot Water, Niger Delta.

I. INTRODUCTION

Production of electric power in Nigeria is insufficient with poor distribution and transmission systems. The poor electricity production in Nigeria is a major contributor to the poor industrial development in the country. Nigeria has one of the lowest net electric power generation per capital in the world. In Nigeria, electricity generation, transmission and distribution account for less than one percent (< 1%) of its GDP but fifty-four percent (54%) of the share of utilities (e.g. electricity and water supply) [1].The Nigerian government-owned and privately operated electricity system currently comprises:

- Three hydro, and fifty-two thermal and one wind generating stations with on-grid licence from Nigerian Electricity Regulatory Commission (NERC), with a total installed capacity of about 25,255MW, and available capacity of 4,978MW, peaking at 5074MW at best of times (actual average generation is about 3800 in 2015).
- A radial transmission grid (330kV and 132kV) owned and managed by the Transmission Company of Nigeria, and
- Eleven distribution companies (33kV and below).

According to the National Population Commission, it was expected that Nigeria's population would hit about 170 million by the end of 2013. Of these, less than 50% currently have access to electricity. The non-utilization or under-utilization of renewable sources such as geothermal energy is one of the causes of insufficient supply of electric power generation and poor/uneven electric power distribution [2].

Geothermal energy involves the tapping of thermodynamic quantities that are equivalent to the capacity of a physical system to produce work/heat. Geothermal energy - heat energy generated and stored in the earth - is generated from the radioactivity decay and continual heat loss from the earth's formation. The temperature difference between the planet and the surface drives a continuous conduction of thermal energy in form of heat from the core to the surface. Rocks and water in the crust is sometimes heated up to 370°C as the temperature at the core – mantle boundary may reach up to 4000°C. This energy can be used for many applications but most importantly to generate electricity. To generate electricity using geothermal energy, a hole is dug into the ground or rock to depths of between 4 – 10 km and water is allowed to flow into this hole and back to the surface. The water reaching the hotter earth crust is heated up and the steam travelling back up to the surface is used to drive turbines which in turn drive generators that produce electricity. For the Niger Delta region, the potential for generating electric power from geothermal resources using hot water from oil wells can be realized in vast areas of the region. According to the World Energy Council, Nigeria produces 120 million tons of oil per year and 4.39Mtoe of gas [3]. All of these oil produced come from the Niger Delta region. This makes the use of renewable energy in the Niger Delta to be greatly encouraged, since geothermal energy production uses very similar equipment and technology to that used by the petroleum industry in their oil and gas production [4].

Heated water is a natural by-product of oil field production processes that has long been considered not usable for power generation. Much of these hot water produced by oil wells each year in the Niger Delta is hot enough to produce electric power through geothermal coproduction. Many of these Niger Delta oil wells have the potential to produce clean energy capacities of several tens of MW. Geothermal-to-electric power energy activity has been utilized in the United States and other developed and developing nations to create electric power. Based on industry announcements and feedback, in early 2014, experts estimated about 12,000 MW of geothermal installed capacity with additions planned [5], and about 30,000 MW of geothermal resources, under development worldwide. Since geothermal sources are considered essentially limitless, estimates of its potential focus on commercial possibilities using quantifiers such as available lands and technology limits. Geothermal resources were estimated to potentially support between 35,448 MW and 72,392 MW of worldwide electrical generation capacity using technology available at the time of a 1999 study. The oil companies operating in the Niger Delta, in partnership with the Nigerian government, could strive to tap into this as part of its energy blend as the potential abound in the region for the realization of this.

This study focuses on the potential use of geothermal energy to power oil field production equipment and providing much needed electric power to communities in and around oil facilities by producing commercial electricity.

2. GEOLOGICAL SETTING AND GEOTHERMAL POTENTIAL OF THE NIGER DELTA

2.1. The Geological Setting

The geological setting of the Niger Delta region has been well documented in various articles [6], [7], [8]. In summary, the Niger Delta is located in the Gulf of Guinea, West Africa, at the culmination of the Benue Trough as shown in figure 1.The Niger Delta is considered as one of the most prolific hydrocarbon provinces in the world [9]. The lithostratigraphy of the Tertiary Niger Delta is classified into three main units – Akata, Agbada and Benin Formations – with depositional environments ranging from marine, transitional and continental settings respectively (see figures 2 and 3 below).

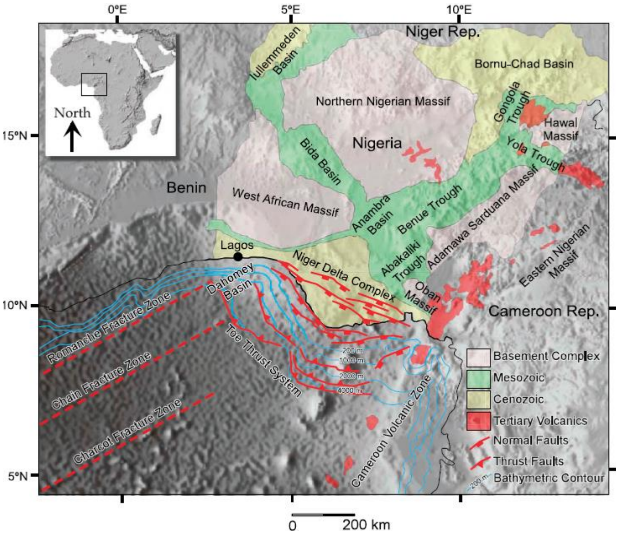

Figure 1: Map of Nigeria showing the main sedimentary basins and tectonic features of the Niger Delta Complex, the Anambra Basin & the Benue Trough [9].

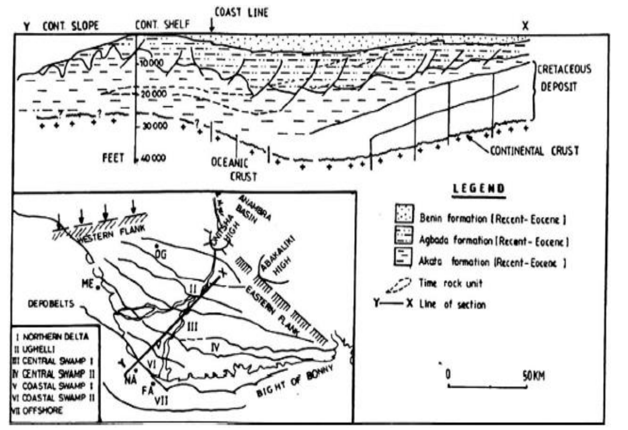

Figure 2: Niger Delta: Stratigraphy and Depobelts [7].

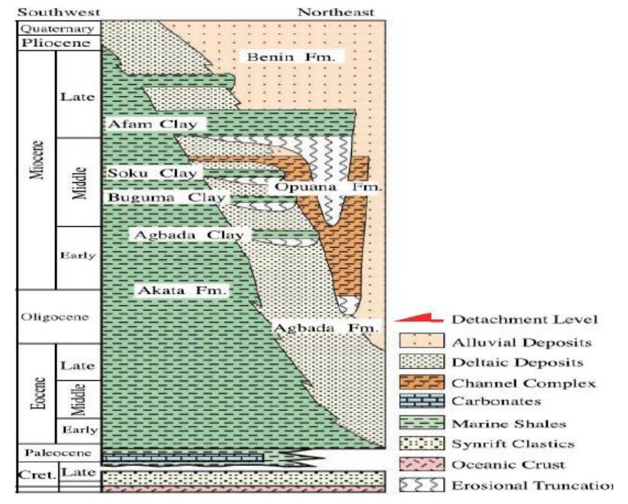

Figure 3: Regional Stratigraphy of the Niger Delta [10], [9]

The Akata, Agbada and Benin Formations overlie stretched continental and oceanic crusts [11], and their ages range from Eocene to recent, but they transgress time boundaries.

The **AKATA FORMATION** is the basal sedimentary unit of the Niger Delta, composed mainly of marine shales. It is believed to be the main source rock for the Niger Delta and the basic unit of the Cenozoic complex. Its thickness ranges from 2000m (6600ft) to 7,000m (23,000ft) [6]. The **AGBADA FORMATION** consists of alternations of sands, sandstones and siltstones. The sandstone is poorly sorted with various grain sizes ranging from fine to coarse, while its sands contributes the main hydrocarbon (oil and gas) reservoir of the Niger Delta. The age of the Formation range from Miocene to late Miocene, while the thickness ranges approximately from 2,880m to 4,200m. The **BENIN FORMATION** is the uppermost limit of the Delta, and overlies the Agbada Formation. It consists of late Eocene to recent deposits of alluvial and upper coastal plain deposits that are up to 2000m thick [12].

2.2. The Geothermal Potential

A good knowledge of the geothermal gradients, subsurface temperature distribution and heat flow regime is invaluable in understanding the thermal maturation patterns of sediments as well as the geothermal potential.
The potentials of geothermal power in Nigeria, and the Niger Delta in particular, are high but the required technology is still in the developing stage. Geothermal energy requires drilling deep down into rocks and Earth's crust to gain access to the heat under the Earth crust. Offshore drilling is common in the exploration of crude oil or fossil fuel in Nigeria's oil rich Niger Delta region, as such advantage of this can be taken instead of drilling for conventional geothermal purposes. Electric power from geothermal energy was after wide researches found to be cost effective, reliable, sustainable and environmentally friendly, but has historically been limited to areas near tectonic plate boundaries.
A number of areas indicate the possibility of geothermal system in Nigeria. Records of geothermal gradient shows that many areas in Nigeria are good for geothermal system. These are subject to confirmation using geophysical methods. In the Earth, normal geothermal gradient is between 2°C/100m to 3°C/100m, which implies an average temperature of about 60°C at 2,000m depth [12], [13]. Geothermal gradient above this range is considered good for geothermal system.
On the basis of Bottom Hole Temperature (BHT) data from oil wells in the Niger Delta, it has been found that geothermal gradient in the Niger Delta ranges from 1.3°C/100m to 5.5°C/100m. Several authors have highlighted the geothermal pattern in the Niger Delta using BHT data [12], [14], [15]. Figure 4 show a map of geothermal gradient of Niger Delta. The map was plotted using estimated values of temperature data from oil wells drilled in the offshore and onshore Niger Delta.

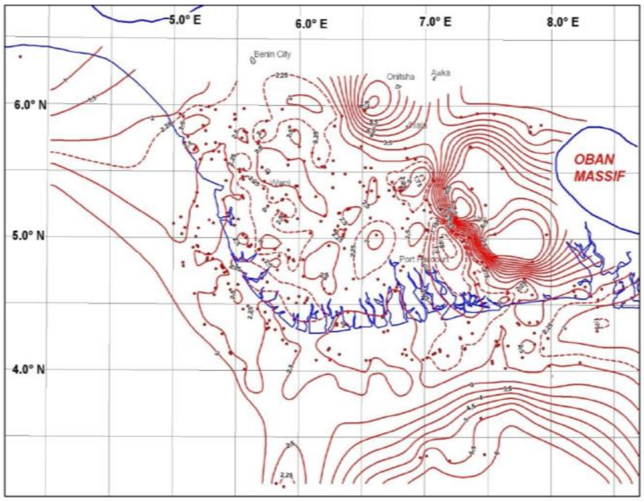

Figure 4: Geothermal gradient of Niger Delta [16].

3. GEOTHERMALENERGY-TO-POWER POTENTIAL AND CAPACITY FROM OIL WELLS

Here we consider and analyze the basic technical aspect of electric power generation from different types of oil wells that, potentially, are capable of supplying geothermal energy from hot water from oil wells. There are three types of oil wells potentially capable of producing hot water from which geothermal energy for electric power can be harnessed. They are:

- A producing oil and gas well with a water cut.
- An oil and gas well abandoned because of high water cut.
- A geopressured brine well with dissolved gas.

The electric power production potential and capacity of a producing oil and gas well with a water cut off is primarily determined by several factors. These factors include the production rate from the oil well or group of oil wells, the temperature of the produced water, the ambient temperature at the field in regard to the temperature of the water, water salinity, and the conversion efficiency of the geothermal electric power plant to be used.
For an abandoned well, the electric power potential and capacity is determined by all the factors fr a producing oil and gas well, in addition with the gas content in the produced fluid, heating value of the gas, and the characteristics of the equipment used to generate electric power from the produced gas. The production rates of hot water and gas from these oil wells depend on the hydraulic properties of the formation, gas content, free as well as dissolved, in the formation water, formation temperature and pressure, and well design.
The electric power potential and capacity from a geopressured brine well is determined by all of the factors considered for an abandoned oil/gas well plus the amount of overpressure in the formation. In this study, we focus on the electric power potential and capacity of the first category, producing oil and gas

wells. As the Niger Delta is considered one of the most prolific hydrocarbon provinces in the world, couple with giant oil discoveries that we have seen in the region, especially in the deep-waters areas, suggesting that the Delta will remain a focus of exploration activities for some time to come. Also, there are numerous oil and gas producing wells currently being operated by International Oil Companies (IOCs) and a few local companies. According to Nigerian National Petroleum Corporation (NNPC), of the 606 oil fields in the Niger Delta area, 355 are on-shore while the remaining 251 are offshore. Of these, 193 are currently operational while 23 have been shut in or abandoned as a result of poor prospectively or total drying up of the wells.

4. ELECTRIC POWER POTENTIAL OF HOT WATER FROM ACTIVE OIL WELLS

Usually hot water that is produced from oil wells along with the hydrocarbons (oil and gas) is separated and injected back. It is, however, possible to extract geothermal energy from the hot water produced, if the temperature of the hot water is adequate, and generate electric power before injecting the water back. The main advantage of this process is that the capital cost of a geothermal electric power project from hot water co-produced from active wells is significantly lower per kilowatt generation capacity than for conventional geothermal electric power project. This is because no additional drilling cost would be involved in such an electric power generation project.

The correlation between the net megawatt (MW) electric power capacity per 1000 gallons per minute (gpm) water rate as a function the water temperature was computed for some wells in the Niger Delta. Figure 5 show the theoretical and empirical correlation based on the thermodynamic simulated model of power plants developed using data from selected wells.

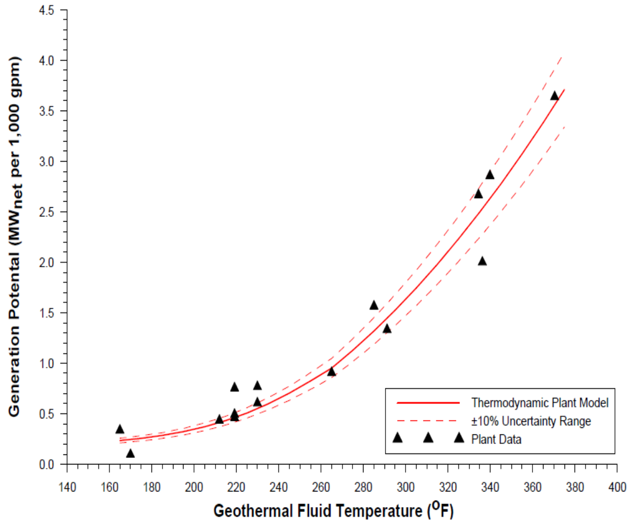

Figure 5: Theoretical and empirical correlation of net power per 1,000 gpm production versus temperature of geothermal water.

This correlation is used to assess the electric power capacity available from the production rate of water of a given temperature. This correlation is done on the assumption that the water is pure i.e. saline-free, however, if there is significant salinity the electric power capacity per gpm would be correspondingly lower. Hydrocarbon fields typically occur in low heat flow areas of the world, usually with a temperature gradient of 1.0F to 2.0F per 100ft. As seen above (section 2.2), the temperature gradient in the Niger Delta region is higher than the world's average for most areas. In addition, the BHT is attractive enough for electric power generation in many sites in the Niger Delta area. But the temperature of the produced hot water at the storage in an oil/gas field is significantly lower than the BHT in the wells. This is due to the heat loss between the wellhead and the storage from the un-insulated surface piping, and heat loss between the bottom and the top of the well as hot water is produced. The estimated wellhead temperature of water with a BHT of 300F at 20,000ft depth is shown in figure 6. From the figure it can be seen that the heat loss from the wellbore is very high at the production rates typical of an oil well – a few hundred to a few thousand barrels per day (B/D). Also, it is observed from the figure that the heat loss effect diminishes with time and essentially reaches equilibrium in a few months. Ambient temperature also influenced the electric power available from a given rate of hot water produced at a given temperature at the storage. The gross electric power available from a given production rate of hot water at a given temperature (in the most likely temperature range for co-produced hot water less than 200F), can be up to double in the Niger Delta. As a result of heat loss between the wellheads and field processing centres, insulating pipelines can increase the net electric power capacity available from oil field sites. If the gas produced from the oil fields is being flared, as is the case in the Niger Delta, the gas could be used instead to pre-heat the geothermal water, hence allowing for the generation of more electric power.

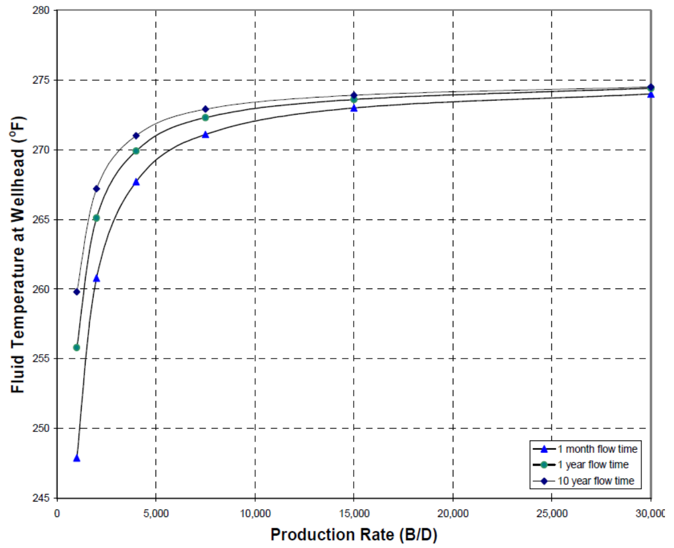

Figure 6: **Reduction in Wellhead Temperature due to heat. loss.**

5. CONCLUSION

Nigeria is blessed with abundant energy resources with great potential for electric power generation yet it's still engrossed with high level of electrical energy deficiency. This has invariably affected development and impinged negatively on the economic growth of the nation. There is a great prospect for electric power generation through the abundant geothermal resources as describes in this research if the associated challenges hampering the technological advancement and the lack of political will to explore and do the right things are surmounted.

52 of the 56 electrical power projects in Nigeria are thermal, but thermal electrical power comes with high environmental pollution. Hence, further construction of thermal electric power generating stations in Nigeria, especially the Niger Delta should be discouraged.

The analyses clearly show the potentials of managing the natural resources in the Niger Delta to cater for its growing energy demand and that of Nigeria, and consequently her economic development. The estimates are feasible and the economic involved in executing the projects is highly objective. The analysis show the feasibility of 5000MW geothermal electrical power in Nigeria and the Niger Delta. The estimated electric power potential from geothermal energy that are feasible in Nigeria cannot be over-emphasized. Going by the estimate, a total of 5000MW can be conveniently generated from hot water produced from oil wells in the Niger Delta. Geothermal power is reliable and sustainable, as the earth's internal heat content of 1031 joules is 100 billon times current worldwide energy consumption. If geothermal water is used to offset electric power generation from fossil fuels (diesel or gas) needed to run pumps and other electrical equipment in the field, there would be substantial reduction in the emission of carbon dioxide. One MW-hour of electricity generated from geothermal water rather than diesel will reduce carbon dioxide emission by about 760 kg.

On an annual basis, a 1 MW plant amounts to a reduction in carbon dioxide emission of about 6 thousand metric tons, assuming a plant capacity factor of 90%. It should also be noted that a geothermal power plant has a much higher availability factor (typically 95%) compared to a fossil fuel plant (60% to 70% typical) and needs much less maintenance.

The heat of the Earth is considered infinite; its use is only limited by technology and the associated costs, but the potential is there to provide enough energy to meet the electrical power needs of Nigeria and the Niger Delta. Production and viability in the Niger Delta region of Nigeria wouldn't be much of a problem as research and development uncovers the possibilities.

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