Article title: A Project To Estimate The Power Capacity Of Geothermal Power Plants Based On The Enthalpy Of Geothermal Fluid And Plant Design

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**TITLE: A PROJECT TO ESTIMATE THE POWER CAPACITY OF GEOTHERMAL
POWER PLANTS BASED ON THE ENTHALPY OF GEOTHERMAL FLUID AND
PLANT DESIGN.**

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Abstract

Surface phenomena that signal the presence of viable geothermal energy can be found in various locations in Nigeria. None of these locations have been explored extensively to determine the feasibility of sustainable geothermal energy development for electricity generation or direct heating purposes. In this context, the present study aims to provide insight into the energy potential of such development based on the enthalpy estimation of geothermal reservoirs. This particular project was conducted to determine the power output from a geothermal resource given an estimated enthalpy of the geothermal fluid. The process route chosen for this project is the single-flash geothermal power plant because of the temperature (180°C) and unique property of the geothermal fluid (a mixture of hot water and steam that exists as a liquid under high pressure). The Ikogosi warm spring in Ekiti State, Nigeria was chosen as the site location for this power plant. To support food security efforts in Africa, this project proposes the cascading of a hot water stream from the flash tank to serve direct heat purposes in agriculture for food preservation, before re-injection to the reservoir. The flowrate of the geothermal fluid to the flash separator was chosen as 3125 tonnes/hr . The power output from a single well using a single flash geothermal plant was evaluated to be 11.3 MW^* . This result was obtained by applying basic thermodynamic principles, including material balance, energy balance, and enthalpy calculations. This particular project is a prelude to a robust model that will accurately determine the power capacity of geothermal power plants based on the enthalpy of geothermal fluid, size of geothermal resource, and different plant designs. I hope that the knowledge gained from the study will promote best practices in geothermal engineering and emphasize appropriate planning for, and implementation of, geothermal plants.

Keywords: Geothermal energy, enthalpy, single flash, Ikogosi warm spring, renewable energy in Nigeria.

* 5 MW can power up to 50,000 Kenyan homes (BBC Future, 2021)

Dedication

To my parents, Mr & Mrs Amaechi Oken (my Mufasa and Sarabi).

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Chapter One

1.0 INTRODUCTION AND RESEARCH STATEMENT

1.1 Introduction

Many experts have noted a relationship between the economic development of a nation and its power generation capacity; a nation cannot have one without the other; lack of access to adequate energy contributes to poverty and economic decline (Olaniyan et al, 2018). Africa has abundant renewable energy resources which if safely harnessed could rescue the continent from the present energy challenge and sustain her budding economic growth transformation. (L. Durito, 2019).

The Africa Development Bank (AfDB) estimates the renewable energy potential in the continent to be 110 GW for wind energy, 15 GW for geothermal energy, 1000 GW for solar energy, and 350 GW for hydroelectricity (Hafner M, et al, 2018). Nigeria has an estimated 93,950 MW (approx. 94 GW) as untapped renewable energy (UN ECA, 2017).

Nigeria, the most populated country in Africa has less than 40% of its populace connected to the electricity grid; those that are connected (less than 40% of the population) hardly enjoy long hours of uninterrupted power supply (Abubakar S et al, 2013). The rest of the population either generate electricity for themselves using generators or abandon electricity use completely.

The country has an estimated population of 206 million (National Population Commission, 2021) with an installed energy capacity of 12, 522 MW; however, only about 30% of this installed capacity (4,000 MW) is functional on most days (USAID, 2021). A bulk of this capacity is contributed by coal, hydroelectric power, and natural gas sources (figure below). Nigeria requires an additional 50,000 MW to adequately light up the nation (World Energy Outlook, 2014).

Figure 1.1 Energy Sources in Nigeria (Energy Commission of Nigeria, 2015)

1.0.1 Geothermal Energy in Nigeria and Africa

Geothermal energy is a renewable and clean energy resource with infinite potential to adequately bridge the energy gap in Nigeria. Compared to other renewable energy sources, geothermal energy is relatively cheaper and readily available, showing no intermittency like solar or wind energy (ThinkGeoEnergy, 2020). The advancement of geothermal energy development in Nigeria (despite various surface manifestations) has been limited by a lack of adequate knowledge among policymakers, entrepreneurs, and local communities in Nigeria about the immense potential and benefits of geothermal energy (IRENA, 2015).

The situation is different in some other parts of Africa. In the 1950s, Kenya began exploration for geothermal energy development and built its first geothermal power plant - *Olkaria* in 1981 (ThinkGeoEnergy, 2020). Due to this early start, (barely five decades after the first geothermal plant was installed in 1904, Italy) Kenya is currently the eighth largest geothermal energy producer in the world, with an installed capacity of 707+ Mwe, only behind nations like the United States, Indonesia, Philippines. Geothermal energy is the second-largest contributor to Kenya's energy grid. (BBC Future, 2021). Geothermal energy development in Kenya is said to have reduced the cost of power in the nation by 22% and 35% for domestic and industrial consumers respectively. (Thinkgeoenergy, 2020).

Other countries in Africa that have made significant progress to harness this abundant energy resource include Ethiopia, Tanzania, Uganda, Rwanda, Comoros, Djibouti, Eritrea, Burundi, Zambia (L. Durito, 2019). The target by Kenya is to harness up to 5000MW of geothermal

energy by 2030. Similarly, Ethiopia is targeting an additional one gigawatt (1GW) of geothermal energy through the Corbetti Power Project (World, Energy Outlook, 2014).

Currently, the only major source of renewable energy in Nigeria is hydroelectric power (HEP). Of all viable hydroelectric power resources available in Nigeria, only the Kanji dam, Jebba hydropower station, and Shiroro Power Station is functional and represents about 10 % of installed energy capacity in Nigeria (ICE, 2018). The rest serve merely as tourist centers (Premium Times, 2017).

In this context, the present study offers insight into the potential of geothermal energy in Nigeria to contribute in no small way to electricity generation thereby reducing over-reliance on fossil fuels and mitigating environmental pollution due to carbon emission. This study aids the sustainable development of geothermal energy by providing insight into the feasibility of pursuing a geothermal reservoir when the enthalpy of geothermal reservoirs is known or can be accurately estimated.

1.2 Objectives of Design project

This project work was carried out:

- To calculate the power capacity of a single flash geothermal power plant based on enthalpy/temperature of fluid from an unexplored geothermal reservoir.

1.3 Significance of work

The economic growth and development of a nation is directly proportional to the amount of energy that nation produces (Olaniyan K et al, 2018). Nigeria has the highest number of people without access to electricity in Africa. According to a division of the United Nations, Nigeria is estimated to reach a population of over 250 million by 2030, and 400 million by 2050; at this rate, Nigeria will become the third-largest nation in the world (National Population Council, 2021). If nothing is done, the number of people without access to energy will significantly increase leading to further economic decline.

Nigeria's energy demand is barely met, especially in the densely populated northern part of the nation; the future looks bleak because, without proper exploration of other abundant (renewable) energy resources, a large percentage of her populace (over 100 million) will not be connected to the electricity grid. (Olaniyan K et al, 2018).

A lot of studies have been done in the past to discuss the potential for geothermal energy in Nigeria and recommend further exploration to determine the feasibility of sustainable development. The present study evaluates the power capacity of a single flash geothermal power plant based on the estimated enthalpy of a geothermal reservoir. This is a timely contribution because currently, geothermal energy is gaining more support from governments.

Although the power capacity of the single flash geothermal power plant was done applying basic thermodynamic principles (material balance, energy balance, and enthalpy calculations), the project is only a prelude to a robust model that will accurately estimate the power capacity of geothermal power plants based on enthalpy of geothermal resource, size of geothermal resource, and design type.

The fluid temperature from an unexplored geothermal reservoir in Ikogosi warm spring (Ekiti State, Nigeria) was estimated to be 188°C. Using a single flash geothermal power plant design, and applying basic thermodynamic principles, the power capacity of the geothermal power plant was calculated to be 11.3 MW*.

5MW can power up to 50,000 Kenyan homes (BBC Future, 2021)

1.4 Process route

The process routes available for this project include the different technologies available for utilizing geothermal energy for electricity generation: Dry steam process, Flash steam process (single flash and double flash processes), and Binary process or Organic Rankine Cycle (ORC).

The process route selected for this design is the single flash steam process.

1.4.1 Process route justification

The single-flash process route is suitable because of the properties of the geothermal reservoir located around the Ikogosi warm spring. The geothermal fluid is assessed to be a high-pressure mixture of brine and steam, existing as liquid because of its high pressure. Because of this, it cannot be used directly in a simpler dry steam power plant, hence it is introduced to a flash separator where the pressure is lowered and a percentage of the mixture flashes rapidly (with enough pressure) to steam. The steam is then used to drive a turbine for power generation.

The majority of geothermal sources do not produce temperatures that are close to the critical point of water. A temperature between 150 °C and 200 °C is suitable for a single flash process

(Dincer & Ezzat, 2018).

Our geothermal fluid falls in-between at 188 °C.

1.4.2 Process route description

A single flash geothermal power plant operation involves a single stage where the superheated mixture of steam and liquid water is passed through a low-pressure flash separator. When the pressure is lowered, part of the fluid vaporizes and flashes into steam. The steam and liquid are separated; the steam is sent to drive the turbine and the liquid is re-injected underground. After the steam is used to drive the turbine, it is condensed back to a liquid in a cooling tower before reinjection into the reservoir (Ronald Dippro, 2016).

For this particular project, the hot liquid is sent to a nearby food preservation plant for further heat to be extracted before re-injection.

1.5 Site Location Justification

The area around Ikogosi was chosen as the site location because of the presence of warm spring in that location. The temperature of the warm spring reaches as high as 70°C at the source of the spring (Ayodele, et al, 2019). Going by subsurface geothermal gradient data from oil drilling and borehole temperature in the southwestern region of Nigeria, 4.0 - 4.5 °C /100m (Akpabio, et al, 2003), the well-depth will be about 3km – 4km to get a temperature of 188°C which is typical of geothermal wells.

1.6 Limitations of the project

The limitations of the project work include:

- No single geothermal power plant exists in Nigeria
- No exploration or drilling has been carried in promising locations to determine the feasibility of geothermal energy development.
- Geothermal fluid conditions (temperature, pressure, flowrate) used for calculation are based on estimation and secondary sources. No site visit was done.

Chapter Two

2.0 Classification of Geothermal Reservoirs

Enthalpy and chemistry are key factors that determine the efficient utilization of a geothermal resource. Both factors depend on the geothermal system from which the fluid originated.

2.0.1 Enthalpy of geothermal fluid

Some authors classify geothermal resources based on temperatures while others have used enthalpy (Dickson and Fanelli, 1990). Enthalpy gives us an idea of the thermal energy or 'value' of fluids in terms of energy. Geothermal resources are classified into low, medium, and high enthalpy (or temperature) resources, according to criteria that are generally based on the heat content of the fluids and their potential forms of utilization.

The following classification by Muffler and Cataldi, 1978 (Dickson and Fanelli, 1990) was used for the purpose of this project.

Table 2.1 *Classification of geothermal resources based on enthalpy*

low temperature	(< 90°C)
medium temperature	(90-150°C)
high temperature	(>150°C)

The uses of geothermal resources depend on their heat content. High-temperature geothermal resources are mainly used for electricity production; medium-temperature resources are also used for electricity production in binary units and direct heating, while low-temperature resources are mainly for direct heating (M. Mburu, 2009).

Going by the classification by Muffler and Cataldi, our geothermal fluid temperature, 188°C is a high-temperature geothermal resource.

2.1 GEOTHERMAL POWER PLANTS

This refers to plants built around the geothermal reservoirs for electricity generation.

The process generally involves drilling a well into the geothermal reservoir and allowing the geothermal fluid to either flow naturally to the surface or use a pump to cause the upward flow. There are different ways of utilizing this steam for power generation, and each process depends on the energy content of the fluid.

2.1.1 Types of Geothermal Plants

There are three main designs that a geothermal power plant can take, these are

- Dry steam power plants
- Flash steam power plants (Single flash and Double flash)
- Binary cycle power plants

2.1.2 Dry Steam Power Plants

Dry steam power plants are the oldest and simplest type of geothermal power plant. The first time this technology was used was in 1904 where it powered electric railroads at Lardarello in Italy. Dry steam power plants utilize high-temperature steam formations to directly provide the energy to drive power generator turbines. The 'dry steam' power plant process typically involves passing high-pressure steam from the reservoir through a rock catcher, and then to the power generator turbines (US, DOE).

The dry steam power plant is suitable where the geothermal steam is not mixed with water. Our geothermal fluid for this project is assessed to be a mixture of hot water and steam.

Figure 2.1 Dry steam power plant

Interesting facts about Dry steam plants:

- About 6 percent of the energy used in northern California is produced at 28 dry steam reservoir plants found at The Geysers dry steam fields in northern California.
- At peak production, these dry steam geothermal power plants are the world's largest single source of geothermal power producing up to 2,000 megawatts of electricity per hour.
- That is about twice the amount of electricity a large nuclear power plant can produce.

2.1.3 Flash steam power plants

The flash steam power plant utilizes a lower temperature geothermal fluid than the dry steam power plants for power generation. There is a higher amount of liquid-dominated geothermal fields than dry steam fields and the presence of liquid phase causes significant efficiency losses in traditional turbines (R. Dipppo, 2011).

The flash steam power plants are classified into single flash power plants and double flash power plants, indicating the number of times the steam-water mixture is passed through a flash drum.

i. Single flash steam power plant

This design was chosen for this project. In a single flash steam power plant, the superheated mixture of steam and liquid water is passed through only one low-pressure flash separator. As the pressure is lowered in the flash drum, part of the fluid vaporizes and flashes into steam. The steam is sent to the turbine for power generation and the liquid is re-injected into the geothermal reservoir (R. Dipppo, 2011).

In this study, since the liquid from the flash process has a lot of heat content, this project proposes that further heat energy should be extracted for food preservation before re-injection. The steam that drives the turbine is cooled and condensed to liquid in a cooling tower before re-injection into the geothermal reservoir.

Figure 2.2 Schematic of a single flash power plant

ii. Double flash steam power plant

The Double-flash steam power plant is a more efficient but complicated design than the single flash plant. For the same geothermal fluid conditions, the double flash process may produce

15-25% more power than a single flash system. The increase in efficiency, however, comes at a higher initial capital cost since the geothermal system is far more complex (R. Dippo, 2011). The double flash process and the single flash process operate under the same principle; the difference lies in how the hot water from the flash is treated. In a double flash process, the hot water is sent to a second flash drum to generate additional steam at a lower pressure before re-injection. The additional steam from the second flash drum is also sent to the turbine for power generation. For more efficient operation, the turbine in this case should be able to effectively utilize the lower pressure steam at an appropriate stage. Another option is to use two separate turbines.

Figure 2.3 A double flash steam power plant with double turbine

2.1.4 Binary cycle power plants

Compared to the other two technologies we've discussed; binary cycle power plants are the latest. This process effectively utilizes a lower geothermal resource. In a binary power plant, moderate to low-temperature geothermal fluid is passed through a heat exchanger to heat a secondary working fluid that generally has a lower boiling point than water.

The geothermal fluid is re-injected into the geothermal reservoir and the heated working fluid is then passed through a turbine for power generation (R. Dippo, 2011).

Examples of working fluids commonly used in binary cycles are ammonia/water mixtures and hydrocarbons. A schematic illustration of the binary power plant is shown below.

Figure 2.4 Binary cycle power plant.

Advantages of the binary cycle process

The binary cycle process offers more flexibility to manage the unique thermodynamics and chemical properties of geothermal resources. Some advantages associated with the binary cycle process include:

- The working fluid is carefully selected to minimize the degradation of the system's machinery. The less equipment that a geo-fluid comes into contact with will minimize the amount of equipment that will be damaged by scaling, corrosion and abrasion over the lifetime of a geothermal power plant. A working fluid that is compatible with the wetted surface of the metal surface extends the lifetime of the plant equipment.
- The lower boiling points of most applicable working fluids allow for the effective utilization of low-temperature geothermal resources.
- There is zero to low emission of harmful gases to the surrounding environment as the used geothermal fluid from the heat exchanger is reinjected to the geothermal reservoir in a closed loop.
- After the working fluid drives the turbine, it is cooled and re-circulated to do its job over and over again.

Chapter Three

3.0 POWER CAPCITY CALCULATION FOR A SINGLE FLASH GEOTHERMAL POWER PLANT

3.1 MATERIAL BALANCE

The following section is the material balance of unit operations in a single flash geothermal power plant to be sited in Ikogosi warm spring, Ekiti State, Nigeria. The thermodynamic properties (temperature and pressure) of the geothermal fluid gotten at a depth of approximately 3km – 4km is estimated at 187.96°C and 12barG respectively.

3.1.1 Material balance for Flash Tank:

Key assumptions:

- That there was about 70% pressure reduction in the flash tank from 12bar to 4bar.
- A basis of 75,000 tonnes of geothermal fluid per day (i.e 3,125 tonnes per hour) was chosen as inlet flow rate to the flash tank.
- Operating conditions at flash tank inlet: Temperature and pressure of geothermal fluid are 187.96°C and 12barG respectively.
- All flowrates are in mass.
- Enthalpy equivalents are obtained using s thermodynamic steam table

More details about the mathematical workings are shown in the appendix section.

i. Steam quality

The percentage of the fluid that separates or flashes into steam in a flash tank when pressure is lowered can be calculated as thus:

$$\text{flash\% or steam quality}(x) = \frac{(h_{f1} - h_{f2})}{h_{fg}}$$

Where:

- h_{f1} : the enthalpy of the inlet hot water and steam mixture from the geothermal well that is delivered to the flash separator.
- h_{f2} : the enthalpy of outlet stream from the flash separator and
- h_{fg} : the latent heat of steam at the first stage flash vessel pressure

From the thermodynamic steam table:

$$h_{f1} @ 12barG = 785.67 \text{ kJ/kg}$$

$$h_{f2} @ 4\text{barG} = 600.37 \text{ kJ/kg}$$

$$h_{fg} @ 4\text{barG} = 2132.95 \text{ kJ/kg}$$

$$\text{Therefore, steam quality}(x) = \frac{(785.67 - 600.37)}{2132.95}$$

$$= 0.0869$$

$$\text{flash}\% \approx 8.7 \%$$

This means that approximately 8.7 % of the geothermal fluid converted to steam in the flash tank due to a 70% reduction in pressure.

- ii. The amount of fluid that is sent to the turbine is only 8.7 % of the inlet flow rate.

$$8.7\% \text{ of feed } 3125 \frac{\text{tonnes}}{\text{hr}} = 271.875 \text{ tonnes/h}$$

- iii. To get the bottom stream, balance the material using: ($F = S + W$)

Where:

- The feed stream is designated **F**,
- The steam mass flowrate as **S**
- And the bottom stream as **W**.

The bottom streamflow can be calculated by: $F - S = W$

$$3125 \frac{\text{tonnes}}{\text{hr}} - 271.875 \frac{\text{tonnes}}{\text{hr}} = 2853.125 \frac{\text{tonnes}}{\text{hr}}$$

Our flash steam tank balance now looks like this.

Table 3.1 Flash tank material balance

Component	Mass Flowrates(tonnes/hr)
Feed	3125
Steam	271.875
Brine/liquid	2853.125

Note: High-temperature condensate contains excess energy which prevents it from remaining in liquid form at a lower pressure. Hence, when the pressure is lowered, the excess energy causes a percentage of the condensate to flash.

3.1.2 Material balance for Turbine

The turbine inlet enthalpy is a function of steam inlet pressure

i. Operating conditions at inlet:

$$h_1 = 2737.63 \text{ kJ/kg} \text{ specific enthalpy of steam @ } 4\text{bar}.$$

ii. Operating conditions at outlet:

$$h_2 = 2584.78 \frac{\text{kJ}}{\text{kg}} \text{ specific enthalpy of steam @ } 0.1\text{bar}$$

Where:

- h_1 = the enthalpy of the steam at inlet conditions
- h_2 = the enthalpy of the steam at outlet conditions

Turbine balance/output is calculated by: $W = h_1 - h_2$

$$2737.63 \frac{\text{kJ}}{\text{kg}} - 2584.78 \frac{\text{kJ}}{\text{kg}}$$

$$= 152.85 \frac{\text{kJ}}{\text{kg}}$$

Table 3.2 Turbine Material balance

Component	Enthalpies(kJ/kg)
Inlet	2737.63
Outlet	2584.78
Work	152.85

3.2 ENERGY BALANCE:

In addition to the assumptions made during the material balance, we can add;

- That the loss of heat in the transfer lines from flash tank to turbine is negligible.
- The enthalpy from the reservoir to the flash tank remained constant

Note: Mass flowrates are represented in kg/s by multiplying flowrates in

$$\text{tonnes/hr by } 1000\text{kg/1tonne} \times 1\text{hr}/3600\text{s}$$

3.2.1 Energy balance at the flash tank:

The pressure and temperature operating conditions are maintained.

Note: Energy flow is a function of enthalpy.

i. Energy flow at the inlet is calculated by:

$$Q_{in} = h_{f1} \times \text{mass flowrate}$$

Where:

- h_{f1} is the inlet enthalpy to the flash tank

Convert flow rate at the inlet from tonnes/hr to kilogram/second:

$$3125 \frac{\text{tonnes}}{\text{hr}} \times \frac{1000\text{kg}}{1\text{tonne}} \times \frac{1\text{hr}}{3600\text{s}}$$

From thermodynamic steam table: Enthalpy at inlet = 785.67 kJ/kg

$$\begin{aligned} \text{Therefore, inlet energy flow} &= 785.67 \frac{\text{kJ}}{\text{kg}} \times 868 \frac{\text{kg}}{\text{s}} \\ &= 681,961.56 \text{ kJ/s} \\ Q_{in} &\sim 682 \text{ MJ/s} \end{aligned}$$

ii. Energy flow at the steam section is calculated by:

$$Q_s = \text{mass flowrate} \times l$$

Where:

- l is referred to as latent heat of vaporization. It was obtained at the flash tank pressure (4 bar).

Convert flow rate at the inlet from tonnes/hr to kilogram/second:

$$\text{Flowrate at steam section: } 271.875 \frac{\text{tonnes}}{\text{hr}} \times \frac{1000\text{kg} \times 1\text{hr}}{1\text{tonne} \times 3600\text{s}}$$

$$75.5 \frac{kg}{s}$$

$$\text{Latent heat of vaporization at flash pressure} = 2132.95 \frac{kJ}{kg}$$

$$\begin{aligned} \text{Energy flow} &= 75.5 \frac{kg}{s} \times 2132.95 \frac{kJ}{kg} \\ &= 161,037.725 \text{ kJ/s} \end{aligned}$$

$$Q_s \sim 161 \text{ MJ/s}$$

iii. The energy flow at the bottom stream can be calculated in the same way:

$$Q_w = h_{f2} \times \text{mass flowrate}$$

$$\begin{aligned} \text{flowrate at bottom stream} &= 2853.125 \frac{\text{tonnes}}{\text{hr}} \times \frac{1000 \text{ kg} \times 1 \text{ hr}}{1 \text{ tonne} \times 3600 \text{ s}} \\ &= 792.535 \frac{kg}{s} \end{aligned}$$

$$\begin{aligned} \text{therefore, energy flow} &= 600.34 \frac{kJ}{kg} \times 792.535 \frac{kg}{s} \\ &= 475,790.463 \frac{kJ}{s} \end{aligned}$$

$$Q_w = 476 \text{ MJ/s}$$

If we perform our balance, we should expect the energies in the output streams to be equal to the energy in the input stream i.e $Q_{in} = Q_s + Q_w$ but that is usually not the case for energy systems.

In reality, no energy system has 100% efficiency. And because energy systems are irreversible, part of the energy is lost during the process. The energy lost is referred to as lost work.

Performing our balance to get the lost work: First, let us get the work that should have been done in an ideal situation. Ideally, the steam energy flow should have been $Q_{in} - Q_w = Q_s$

$$\text{i.e. } 682 \text{ MJ/s} - 476 \text{ MJ/s} = 206 \text{ MJ/s}$$

206 MJ/s is referred to as reversible work W_{REV} , But in reality, the energy flow of steam is: **161 MJ/s**. That is because heat cannot fully be converted to work and will always be lost to some degree. **161 MJ/s** is referred to actual work done by the system W_{ACTUAL}

Therefore, the lost work can be obtained by:

$$W_{LOST} = W_{REV} - W_{ACTUAL}$$

$$= 206 \text{ MJ/s} - 161 \text{ MJ/s}$$

$$= 29 \text{ MJ/s}$$

Table 3.3 Flash tank Energy balance

Component	Energy flow (MJ/s)
Feed	682
Steam	162
Brine	476

3.2.2 Turbine Output Work

The turbine output energy is a function of inlet pressure to the turbine Assuming that:

- There was no enthalpy change from the flash separator to the turbine inlet
- The steam was delivered to the turbine at a pressure of exactly 4bar

Table 3.4 Turbine Energy Balance

Component	Energy flow(MJ/s)
Feed	161

Work	11.5
------	------

The turbine output energy can be calculated by:

$$W = m (h_1 - h_2)$$

Where:

- h_1 and h_2 are inlet and outlet enthalpies respectively
- m is the mass flowrate

From our previous balance, we have:

$$h_1 - h_2 = 152.85 \text{ kJ/kg}$$

$$\text{Therefore } W = 75.5 \text{ kg/s} \times 152.85 \text{ kJ/kg}$$

$$W = 11540 \frac{\text{kJ}}{\text{s}}$$

$$W = 11.5 \text{ MJ/s}$$

3.2.3 Efficiency

The turbine efficiency or power plant efficiency is the ratio between power generated to the heat flow to the turbine/power plant.

$$\begin{aligned} \text{Efficiency} &= \frac{W}{Q_{in}} \\ &= \frac{11.5}{161} \\ &= 0.0714 \\ &\sim 7.14 \% \end{aligned}$$

The above efficiency is typical of a power generation system from steam plants.

This means up to 90% of the energy of the geothermal steam is discarded as wasteheat. This presents a strong argument here for the use of geothermal resources for direct applications such as district heating (for example food preservation by drying) instead of power generation, when economically feasible. (Radmehr, 2005)

3.2.4 Generator Power Output

Using a generator with 98% efficiency, the power output can be calculated.

$$\text{Power output} = \text{Energy output} \times \text{Generator efficiency}$$

$$\text{since } 1 \frac{J}{s} = 1 \text{ watt}$$

Power capacity of our geothermal plant = 11.3 MW

Figure 3.1 Plant and Instrumentation Diagram for geothermal plant utilizing heat for electricity generation and food preservation by drying

Chapter Four

4.0 DISCUSSION

4.1 Geothermal Energy Utilization

Geothermal energy can be utilized for electricity generation, and direct heat purposes in form of geothermal heat pumps (for cooling and heating buildings), in agriculture for food preservation, and so on.

Our focus in this project is to emphasize how geothermal energy can be used for safe power generation as well as effective food preservation. The numbers are alarming on the amount of food that is being wasted due to poor preservation methods. What makes it worse is that a large population of the world faces food shortages and scarcity (FAO, 2015). Geothermal energy development can contribute to the preservation of food and mitigation of food waste.

4.1.1 Use of Geothermal Energy in Food and Agriculture; Opportunities for Developing Countries

For four decades, Iceland has shown the world how to enhance food security by food preservation utilizing the heat stored in abundance in our earth (FAO, 2015). As the number of people to feed continues to increase in leaps and bounds globally, it's time to seek guidance from the pioneering developments and technology in Iceland to secure food that is currently wasted due to a lack of effective storage or preservation methods. When applied on a global scale, drying technology has the potential to increase the availability of food by up to 20 percent. No other single method holds such potential. (FAO, 2015).

Figure 4.1 Tomatoes loaded on drying racks (source: FAO)

Low to moderate temperature geothermal resources including waste heat and cascading from power plants are the sources of geothermal energy for agricultural and agro-industrial uses.

4.2 Geothermal Energy in Food Drying

The thermal drying process is popular among many agricultural and food industries as an effective food preservation method (Senadeera et al. 2005). Drying is an important food preservation method that has the potential to avoid wastage and ensure the availability of nutritious food all year round, and during droughts.

Examples of food preserved by drying include (FAO, 2015):

Figure 4.2 *Cultivation of Spirulina using geothermal energy in Nigrita, Greece (source: FAO)*

Figure 4.3 *Fish drying in Iceland (source: FAO)*

Other examples include:

- Bean and grain drying in Indonesia
- Onion and garlic drying in the United States
- Chilli and garlic drying in Thailand
- Cotton drying in Greece
- Rice drying in the former Yugoslav Republic of Macedonia
- Pyre-Brum, tobacco and maize drying in Kenya
- Fruit drying in Mexico
- Tomatoes are dried using geothermal hot water at 59 °C in Greece.

4.2.1 Sterilization processes

In a wide range of industries such as meat and fish canning, sterilization is an important step

to eliminate the growth of bacteria, particularly *Clostridium botulinum*.

The recommended temperature for killing *C. botulinum* bacteria is 121 °C for three (3) minutes. Geothermal steam (or hot water at 105–120 °C) is commonly used to sterilize equipment in the food processing, canning, and bottling industries (Lund, 1996).

4.2.2 Milk pasteurization

When milk is collected, enzyme activity and growth of microorganisms especially under unhygienic production and storage conditions at ambient temperature cause the milk quality to deteriorate rapidly.

To avoid microbial growth and enzyme activity, milk production and processing must be done by pasteurization process or ultra-high temperature (UHT) process (Perko, 2011; Torkar and Golc Teger, 2008). The temperature of the inlet geothermal hot water used in the pasteurization process is about 87 °C and the outlet is 77 °C (Lund, 1997). This is a low-temperature geothermal resource that can be obtained directly from simple production wells or wastewater and cascading from geothermal power plants.

4.2.3 Greenhouses

For the past two decades and a half, the most common use of geothermal energy in agriculture has been in greenhouses. Geothermal heat is currently used especially in many European countries to produce vegetables, fruits, and flowers on a commercial scale in all seasons.

The use of geothermal energy to heat greenhouses has several benefits (Popovski and Vasilevska, 2003):

- Geothermal energy is relatively cheaper than energy from other available sources.
- Geothermal heating systems are relatively simple to install and maintain.
- Greenhouses account for a bulk of agriculture's total consumption of low-enthalpy energy. Greenhouse production areas are sited close to low-enthalpy geothermal reservoirs.
- The use of geothermal energy improves the efficiency of food production by making use of locally available energy sources.

From examples above, this study proposes that low enthalpy geothermal resources that cannot be used to efficiently generate electricity can be channeled to nearby food preservation plants. This is crucial given the alarming rate of population growth and the threat to food security in many regions across the world. Geothermal energy can be safely harnessed to combat this challenge. When applied on a global scale, drying technology has the potential to increase the availability of food by up to 20 percent. No other single method holds such potential. (FAO, 2015)

4.3 CHALLENGES FACING SUSTAINABLE GEOTHERMAL ENERGY DEVELOPMENT

The main constraints and challenges associated with the use of geothermal energy for electricity generation, in agriculture for food preservation are policy and regulatory barriers; technical barriers; and financial barriers.

i.) Policy and regulatory barriers

Government policies and legislation are key factors in creating an enabling environment for the development of geothermal energy.

It wasn't until recently in nations like Japan that government policies were relaxed to promote the development of geothermal energy. For example, the feed-in-tariff for geothermal energy was made higher than other sources of renewable energy, and the 10 years exploratory phase was reduced to 8 years. Also, in Japan, the budget for the upcoming FY 2022 was increased for the exploration and development of geothermal in the nation (thinkgeoenergy, 2021). This was done to aid Japan's goal of having up to 42% of renewable energy by 2030.

Notwithstanding, few governments in favorable geothermal locations still lack clear policies that promote the development of geothermal energy. Also, budgetary allocations to geothermal energy research and development tend to be low in developing countries.

Nigerians don't involve Geothermal Energy Professionals when carrying out Renewable Energy Plans and Policies hence little support exists on the subject in Nigeria.

ii.) Technical barriers

Although geothermal energy development has been on for over a decade now, there is still a relatively low amount of technical expertise in the industry. Being a somewhat new and unknown technology, technical expertise is crucial for developing geothermal systems safely. A critical mass of policy analysts, economic managers, engineers, qualified personnel, and other professionals is required for safe geothermal energy development. This is lacking in most developing countries (Kombe & Muguthu, 2018).

iii.) Financial barriers

The most popular constraint to geothermal energy investment and development especially in resource-constrained economies is the high upfront cost of geothermal energy technologies.

As earlier noted, most developing countries with abundant geothermal resources lack the financial resources to even explore the viability of the development of geothermal systems (Kombe & Muguthu, 2018). However, geothermal energy is a clean energy source that reduces carbon emissions significantly. To support the global clean energy efforts in the face of climate

change, investment in geothermal energy will be a small cost compared to the cost of dealing with the consequences of climate change.

Governments can play a very important role in initiating geothermal projects by financing the early phases (i.e., exploration and appraisal). However, this requires the right policy environment, which is lacking in most cases.

4.4 CONCLUSION

The result from our enthalpy evaluation shows that a single flash power plant with a capacity of approximately 11 MW can be installed in Ikogosi, Ekiti State. A geothermal power plant with a capacity of 5 MW can power up to 50,000 homes in Kenya (Future Planet, 2021).

The scope of this project did not include the cost analysis of the plant from exploration and development to installation, therefore we cannot assess the economic viability of the project. The depth of drill, enthalpy of fluid, and amount of geothermal resource were based on estimation and secondary sources. The evaluation assumed negligible heat losses at various stages during the process. No site visits were done to measure temperature/enthalpy and other design parameters; data used for energy evaluation was based on secondary sources.

The present study argues that if 11 MW power can be obtained from a single well in Ikogosi, then there is immense potential for the sustainable development of geothermal energy in Nigeria.

4.5 FUTURE RESEARCH

Various models have been proposed for estimating the energy potential of geothermal resources. However, these temperature-based-models are limited because they do not consider the size of the geothermal resource (flowrate) and the type of geothermal power plant (design). The present study lays the foundational work for a more robust model that will evaluate power capacity of prospective geothermal power plants considering the enthalpy of the fluid, flowrate and power plant design. This model will be developed using data from primary sources including various geothermal power plants in operation.

I hope that the knowledge gained from the study will promote best practices in geothermal engineering and emphasize appropriate planning for, and implementation of, geothermal plants.

Appendix

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THERMODYNAMIC STEAM TABLE:

Absolute pressure	Boiling point	Specific volume (steam)	Density (steam)	Specific enthalpy of liquid water (sensible heat)		Specific enthalpy of steam (total heat)		Latent heat of vaporization		Specific heat	Dynamic viscosity
				kJ/kg	Kcal/kg	kJ/kg	Kcal/kg	kJ/kg	Kcal/kg		
bar	°C	m ³ /kg	kg/m ³							kJ/kg.K	kg/ms
30	233.84	0.067	15.009	1008.33	240.84	2802.27	669.31	1793.94	428.48	3.4069	0.000017
31	235.66	0.064	15.512	1016.97	242.90	2802.33	669.32	1785.36	426.42	3.4442	0.000017
32	237.44	0.062	16.016	1025.41	244.92	2802.32	669.32	1776.90	424.41	3.4815	0.000017
33	239.18	0.061	16.521	1033.69	246.89	2802.25	669.31	1768.56	422.41	3.5187	0.000017
34	240.88	0.059	17.028	1041.79	248.83	2802.12	669.28	1760.33	420.43	3.5559	0.000017
35	242.54	0.057	17.536	1049.74	250.73	2801.95	669.23	1752.20	418.51	3.5932	0.000017
36	244.16	0.055	18.046	1057.54	252.59	2801.72	669.18	1744.17	416.59	3.6305	0.000017
37	245.75	0.054	18.557	1065.21	254.42	2801.44	669.11	1736.24	414.69	3.6679	0.000017

38	247.31	0.052	19.070	1072.73	256.22	2801.12	669.04	1728.39	412.82	3.7054	0.000017
39	248.84	0.051	19.585	1080.13	257.94	2800.75	668.95	1720.62	410.96	3.7429	0.000018
40	250.33	0.050	20.101	1087.40	259.72	2800.34	668.85	1712.94	409.15	3.7806	0.000018
41	251.80	0.048	20.619	1094.56	261.43	2799.89	668.74	1705.33	407.34	3.8185	0.000018
42	253.24	0.047	21.138	1101.61	263.12	2799.40	668.62	1697.79	405.51	3.8565	0.000018
43	254.66	0.046	21.660	1108.55	264.77	2798.87	668.50	1690.32	403.71	3.8946	0.000018
44	256.05	0.045	22.183	1115.39	266.44	2798.30	668.36	1682.91	401.96	3.9329	0.000018
45	257.41	0.044	22.708	1122.13	268.02	2797.70	668.22	1675.57	400.20	3.9715	0.000018
46	258.76	0.043	23.235	1128.78	269.60	2797.07	668.07	1668.29	398.46	4.0102	0.000018
47	260.08	0.042	23.763	1135.33	271.17	2796.40	667.91	1661.06	396.74	4.0492	0.000018
48	261.38	0.041	24.294	1141.80	272.71	2795.69	667.74	1653.89	395.03	4.0884	0.000018
49	262.66	0.040	24.827	1148.19	274.24	2794.96	667.57	1646.77	393.32	4.1279	0.000018
50	263.92	0.039	25.362	1154.50	275.75	2794.20	667.38	1639.70	391.64	4.1676	0.000018
51	265.16	0.039	25.898	1160.73	277.23	2793.41	667.19	1632.68	389.96	4.2076	0.000018
52	266.38	0.038	26.437	1166.88	278.70	2792.58	667.00	1625.70	388.29	4.2479	0.000018
53	267.58	0.037	26.978	1172.97	280.16	2791.74	666.79	1618.77	386.64	4.2885	0.000018
54	268.77	0.036	27.521	1178.98	281.59	2790.86	666.57	1611.88	384.99	4.3294	0.000018
55	269.94	0.036	28.067	1184.93	283.02	2789.95	666.35	1605.03	383.35	4.3706	0.000018
56	271.09	0.035	28.614	1190.81	284.42	2789.02	666.12	1598.21	381.71	4.4122	0.000018
57	272.23	0.034	29.164	1196.64	285.81	2788.07	665.91	1591.43	380.11	4.4541	0.000018
58	273.36	0.034	29.716	1202.40	287.19	2787.09	665.68	1584.69	378.56	4.4963	0.000019
59	274.47	0.033	30.270	1208.10	288.55	2786.08	665.44	1577.98	376.99	4.5389	0.000019
60	275.56	0.032	30.827	1213.75	289.90	2785.05	665.20	1571.31	375.36	4.5819	0.000019
61	276.64	0.032	31.386	1219.34	291.23	2784.00	664.95	1564.66	373.71	4.6253	0.000019
62	277.71	0.031	31.947	1224.88	292.56	2782.92	664.69	1558.04	372.13	4.6691	0.000019
63	278.76	0.031	32.511	1230.37	293.87	2781.82	664.43	1551.45	370.56	4.7133	0.000019
64	279.80	0.030	33.077	1235.81	295.17	2780.70	664.16	1544.89	368.99	4.7578	0.000019
65	280.83	0.030	33.646	1241.20	296.45	2779.55	663.89	1538.36	367.41	4.8029	0.000019
66	281.85	0.029	34.218	1246.54	297.71	2778.39	663.61	1531.85	365.88	4.8483	0.000019
67	282.85	0.029	34.792	1251.84	299.00	2777.20	663.32	1525.36	364.33	4.8943	0.000019
68	283.85	0.028	35.368	1257.09	300.23	2775.99	663.03	1518.90	362.78	4.9407	0.000019
69	284.83	0.028	35.948	1262.31	301.50	2774.76	662.74	1512.45	361.24	4.9875	0.000019
70	285.80	0.027	36.529	1267.48	302.73	2773.51	662.44	1506.03	359.71	5.0348	0.000019
71	286.76	0.027	37.114	1272.61	303.96	2772.24	662.14	1499.63	358.18	5.0827	0.000019
72	287.71	0.027	37.702	1277.70	305.17	2770.95	661.83	1493.25	356.66	5.1310	0.000019
73	288.65	0.026	38.292	1282.75	306.38	2769.64	661.52	1486.89	355.14	5.1798	0.000019
74	289.59	0.026	38.885	1287.77	307.58	2768.31	661.20	1480.54	353.62	5.2292	0.000019
75	290.51	0.025	39.481	1292.75	308.77	2766.97	660.88	1474.21	352.11	5.2791	0.000019
76	291.42	0.025	40.080	1297.70	309.93	2765.60	660.55	1467.90	350.60	5.3295	0.000019
77	292.32	0.025	40.681	1302.61	311.12	2764.22	660.22	1461.61	349.10	5.3805	0.000019
78	293.22	0.024	41.286	1307.49	312.29	2762.81	659.89	1455.32	347.60	5.4321	0.000019
79	294.10	0.024	41.894	1312.34	313.45	2761.39	659.55	1449.06	346.10	5.4843	0.000019
80	294.98	0.024	42.505	1317.15	314.60	2759.95	659.20	1442.80	344.61	5.5370	0.000019
81	295.85	0.023	43.118	1321.94	315.74	2758.50	658.86	1436.56	343.12	5.5904	0.000020
82	296.71	0.023	43.735	1326.70	316.88	2757.03	658.50	1430.33	341.63	5.6443	0.000020

83	297.56	0.023	44.356	1331.42	318.0	2755.54	658.15	1424.11	340.14	5.6989	0.000020
84	298.40	0.022	44.979	1336.12	319.15	2754.03	657.79	1417.91	338.66	5.7542	0.000020
85	299.24	0.022	45.606	1340.79	320.24	2752.50	657.42	1411.71	337.18	5.8101	0.000020
86	300.07	0.022	46.235	1345.44	321.35	2750.97	657.06	1405.52	335.70	5.8666	0.000020
87	300.89	0.021	46.869	1350.06	322.46	2749.41	656.68	1399.35	334.23	5.9239	0.000020
88	301.71	0.021	47.505	1354.66	323.55	2747.84	656.31	1393.18	332.76	5.9818	0.000020
89	302.51	0.021	48.146	1359.22	324.65	2746.25	655.93	1387.02	331.28	6.0404	0.000020
90	303.31	0.020	48.789	1363.77	325.73	2744.64	655.55	1380.87	329.82	6.0998	0.000020
91	304.11	0.020	49.436	1368.29	326.81	2743.02	655.16	1374.73	328.35	6.1599	0.000020
92	304.89	0.020	50.087	1372.80	327.88	2741.39	654.77	1368.59	326.88	6.2208	0.000020
93	305.67	0.020	50.741	1377.27	328.96	2739.73	654.37	1362.46	325.42	6.2825	0.000020
94	306.45	0.019	51.399	1381.73	330.02	2738.07	653.98	1356.34	323.96	6.3450	0.000020
95	307.22	0.019	52.061	1386.17	331.08	2736.38	653.57	1350.22	322.49	6.4083	0.000020
96	307.98	0.019	52.726	1390.58	332.15	2734.69	653.17	1344.11	321.03	6.4725	0.000020

Absolute pressure	Boiling point	Specific volume (steam)	Density (steam)	Specific enthalpy of liquid water (sensible heat)		Specific enthalpy of steam (total heat)		Latent heat of vaporization		Specific heat	Dynamic viscosity
bar	°C	m ³ /kg	kg/m ³	kJ/kg	Kcal/kg	kJ/kg	Kcal/kg	kJ/kg	Kcal/kg	kJ/kg.K	kg/m.s
0.02	17.51	67.006	0.015	73.45	17.54	2533.64	605.15	2460.19	587.61	1.8644	0.000010
0.03	24.10	45.667	0.022	101.00	24.12	2545.64	608.02	2444.65	583.89	1.8694	0.000010
0.04	28.98	34.802	0.029	121.41	29.00	2554.51	610.13	2433.10	581.14	1.8736	0.000010
0.05	32.90	28.194	0.035	137.77	32.91	2561.59	611.83	2423.82	578.92	1.8774	0.000010
0.06	36.18	23.741	0.042	151.50	36.19	2567.51	613.24	2416.01	577.05	1.8808	0.000010
0.07	39.02	20.531	0.049	163.38	39.02	2572.62	614.46	2409.24	575.44	1.8840	0.000010
0.08	41.53	18.105	0.055	173.87	41.53	2577.11	615.53	2403.25	574.01	1.8871	0.000010
0.09	43.79	16.204	0.062	183.28	43.78	2581.14	616.49	2397.85	572.72	1.8899	0.000010
0.1	45.83	14.675	0.068	191.84	45.82	2584.78	617.36	2392.94	571.54	1.8927	0.000010
0.2	60.09	7.650	0.131	251.46	60.06	2609.86	623.35	2358.40	563.30	1.9156	0.000011
0.3	69.13	5.229	0.191	289.31	69.10	2625.43	627.07	2336.13	557.97	1.9343	0.000011
0.4	75.89	3.993	0.250	317.65	75.87	2636.88	629.81	2319.23	553.94	1.9506	0.000011
0.5	81.35	3.240	0.309	340.57	81.34	2645.99	631.98	2305.42	550.64	1.9654	0.000012
0.6	85.95	2.732	0.366	359.93	85.97	2653.57	633.79	2293.64	547.83	1.9790	0.000012
0.7	89.96	2.365	0.423	376.77	89.99	2660.07	635.35	2283.30	545.36	1.9919	0.000012
0.8	93.51	2.087	0.479	391.73	93.56	2665.77	636.71	2274.05	543.15	2.0040	0.000012
0.9	96.71	1.869	0.535	405.21	96.78	2670.85	637.92	2265.65	541.14	2.0156	0.000012
1	99.63	1.694	0.590	417.51	99.72	2675.43	639.02	2257.92	539.30	2.0267	0.000012
1.1	102.32	1.549	0.645	428.84	102.43	2679.61	640.01	2250.76	537.59	2.0373	0.000012
1.2	104.81	1.428	0.700	439.36	104.94	2683.44	640.93	2244.08	535.99	2.0476	0.000012
1.3	107.13	1.325	0.755	449.19	107.29	2686.98	641.77	2237.79	534.49	2.0576	0.000013
1.4	109.32	1.236	0.809	458.42	109.49	2690.28	642.56	2231.86	533.07	2.0673	0.000013
1.5	111.37	1.159	0.863	467.13	111.57	2693.36	643.30	2226.23	531.73	2.0768	0.000013
1.5	111.37	1.159	0.863	467.13	111.57	2693.36	643.30	2226.23	531.73	2.0768	0.000013
1.6	113.32	1.091	0.916	475.38	113.54	2696.25	643.99	2220.87	530.45	2.0860	0.000013
1.7	115.17	1.031	0.970	483.22	115.42	2698.97	644.64	2215.75	529.22	2.0950	0.000013
1.8	116.93	0.977	1.023	490.70	117.20	2701.54	645.25	2210.84	528.05	2.1037	0.000013
1.9	118.62	0.929	1.076	497.85	118.91	2703.98	645.83	2206.13	526.92	2.1124	0.000013
2	120.23	0.885	1.129	504.71	120.55	2706.29	646.39	2201.59	525.84	2.1208	0.000013
2.2	123.27	0.810	1.235	517.63	123.63	2710.60	647.42	2192.98	523.78	2.1372	0.000013
2.4	126.09	0.746	1.340	529.64	126.50	2714.55	648.36	2184.91	521.86	2.1531	0.000013
2.6	128.73	0.693	1.444	540.88	129.19	2718.17	649.22	2177.30	520.04	2.1685	0.000013
2.8	131.20	0.646	1.548	551.45	131.71	2721.54	650.03	2170.08	518.32	2.1835	0.000013
3	133.54	0.606	1.651	561.44	134.10	2724.66	650.77	2163.22	516.68	2.1981	0.000013
3.5	138.87	0.524	1.908	584.28	139.55	2731.63	652.44	2147.35	512.89	2.2331	0.000014
4	143.63	0.462	2.163	604.68	144.43	2737.63	653.87	2132.95	509.45	2.2664	0.000014
4.5	147.92	0.414	2.417	623.17	148.84	2742.88	655.13	2119.71	506.29	2.2983	0.000014
5	151.85	0.375	2.669	640.12	152.89	2747.54	656.24	2107.42	503.35	2.3289	0.000014
5.5	155.47	0.342	2.920	655.81	156.64	2751.70	657.23	2095.90	500.60	2.3585	0.000014
6	158.84	0.315	3.170	670.43	160.13	2755.46	658.13	2085.03	498.00	2.3873	0.000014
6.5	161.99	0.292	3.419	684.14	163.40	2758.87	658.94	2074.73	495.54	2.4152	0.000014
7	164.96	0.273	3.667	697.07	166.49	2761.98	659.69	2064.92	493.20	2.4424	0.000015
7.5	167.76	0.255	3.915	709.30	169.41	2764.84	660.37	2055.53	490.96	2.4690	0.000015
8	170.42	0.240	4.162	720.94	172.19	2767.46	661.00	2046.53	488.80	2.4951	0.000015
8.5	172.94	0.227	4.409	732.03	174.84	2769.89	661.58	2037.86	486.73	2.5206	0.000015
9	175.36	0.215	4.655	742.64	177.38	2772.13	662.11	2029.49	484.74	2.5456	0.000015
9.5	177.67	0.204	4.901	752.82	179.81	2774.22	662.61	2021.40	482.80	2.5702	0.000015
10	179.88	0.194	5.147	762.60	182.14	2776.16	663.07	2013.56	480.93	2.5944	0.000015
11	184.06	0.177	5.638	781.11	186.57	2779.66	663.91	1998.55	477.35	2.6418	0.000015
12	187.96	0.163	6.127	798.42	190.70	2782.73	664.64	1984.31	473.94	2.6878	0.000015
13	191.60	0.151	6.617	814.68	194.58	2785.42	665.29	1970.73	470.70	2.7327	0.000015
14	195.04	0.141	7.106	830.05	198.26	2787.79	665.85	1957.73	467.60	2.7767	0.000016
15	198.28	0.132	7.596	844.64	201.74	2789.88	666.35	1945.24	464.61	2.8197	0.000016
16	201.37	0.124	8.085	858.54	205.06	2791.73	666.79	1933.19	461.74	2.8620	0.000016
17	204.30	0.117	8.575	871.82	208.23	2793.37	667.18	1921.55	458.95	2.9036	0.000016
18	207.11	0.110	9.065	884.55	211.27	2794.81	667.53	1910.27	456.26	2.9445	0.000016
19	209.79	0.105	9.556	896.78	214.19	2796.09	667.83	1899.31	453.64	2.9849	0.000016
20	212.37	0.100	10.047	908.56	217.01	2797.21	668.10	1888.65	451.10	3.0248	0.000016
21	214.85	0.095	10.539	919.93	219.72	2798.18	668.33	1878.25	448.61	3.0643	0.000016
22	217.24	0.091	11.032	930.92	222.35	2799.03	668.54	1868.11	446.19	3.1034	0.000016
23	219.55	0.087	11.525	941.57	224.89	2799.77	668.71	1858.20	443.82	3.1421	0.000016
24	221.78	0.083	12.020	951.90	227.36	2800.39	668.86	1848.49	441.50	3.1805	0.000017
25	223.94	0.080	12.515	961.93	229.75	2800.91	668.99	1838.98	439.23	3.2187	0.000017
26	226.03	0.077	13.012	971.69	232.08	2801.35	669.09	1829.66	437.01	3.2567	0.000017
27	228.06	0.074	13.509	981.19	234.35	2801.69	669.17	1820.50	434.82	3.2944	0.000017
28	230.04	0.071	14.008	990.46	236.57	2801.96	669.24	1811.50	432.67	3.3320	0.000017
29	231.96	0.069	14.508	999.50	238.73	2802.15	669.28	1802.65	430.56	3.3695	0.000017
30	233.84	0.067	15.009	1008.33	240.84	2802.27	669.31	1793.94	428.48	3.4069	0.000017