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Investigation of the Potentials of Heat Extraction from Abandoned Oil Wells for Electricity Generation

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Abstract

In the era of high energy demand caused by rapid population growth, renewable energy is required in the energy mix for the sustainability of both human and industrial development. This paper investigates the potential of extracting heat energy from abandoned oil and gas wells for electricity production. Four wells located in the Niger Delta were considered. Each well has its properties and steam flow rates. The geothermal reservoir was modeled as a liquid-vapor-dominated system at in situ reservoir conditions. The fluid temperature in the reservoir was determined to be 170°C in the reservoir. Equations describing geothermal resource potentials, energy flow in a wellbore, and gross electrical power production using turbines were presented. A Single-flash turbine system was used because steam was produced in the reservoir. MATLAB software was used in the simulation of the heat transfer process. The results showed that the geothermal energy corresponding to the reservoir considered was 2.45 x 10^{12} Joules. The electricity production result showed that there was a reduction in gross electrical power output due to an increase in sink temperature, while the relationship between gross electrical power output and separator temperature was such that there was an initial increase in gross electrical power output due to an increase in separator pressure until an optimum point was reached wherein further increase in separator pressure progressively decreased the value of the gross electrical power output. The optimum separator temperatures for well 1, well 2, well 3, and well 4 were 120°C, 120°C, 110°C, and 105°C respectively at a sink temperature of 45°C. Because of the high reservoir pressure used, the separator pressure was higher than the actual reservoir pressure. Proper understanding of heat flow which enables accurate estimation of heat production is necessary to maximize heat extraction from the reservoir. The simulation conducted reveals that geothermal resources holds great potentials for electrical energy generation and should be put to developmental use in Nigeria as a means to increase the total power generation and increase the portion of renewables in Nigeria energy value chain.

***Keywords**: Geothermal energy Extraction; Turbine; Abandoned oil and gas wells; Fluid dominated; Heat transfer; Electric power generation; Renewable energy.*

1. Introduction

Renewable energy resources have demonstrated great potentials as the most efficient and effective solutions to global environmental problems and with promises of long-term sustainable development. Diversified and sustainable energy resources are wholly indispensable in the fight against global climate change and looming world environmental issues [1] and global energy demand. The reduction in fossil fuel usage and increased attention to renewable and alternative energies such as solar, wind, geothermal energies are considered as a transition to a global green energy future (ultra-low or no carbon footprints). Geothermal energy can be regarded as the most promising sustainable energy given its abundant storage and reliable sources [1].

Geothermal energy is renewable energy found beneath the earth's surface. It is a source of thermal energy whose generation and storage are within the earth's crust. The geothermal energy stored in the earth's crust is inexhaustible considering human standards and needs. It has a much less expensive production capability and much pollutant-free during its production or extraction. Furthermore, another peculiar advantage of geothermal energy extraction is that it is not affected by weather conditions like solar and wind.

Geothermal energy can also be used in district heating and agriculture. A geothermal system consists of a reservoir, a heat source, and a carrier fluid that transfers the heat [2]. Thus a geothermal system can be grouped into three main systems namely hydrothermal, geo-pressured and hot dry rock systems depending on the heat transfer medium. Hydrothermal systems which are dominated by vapor and hot water are further classified as conventional geothermal resources while hot dry rocks are classified as non-conventional resources [3]. The unconventional resources have been shown to have higher potentials for geothermal development because they exist at very high temperatures and heat storage. The heat storage of hot dry rocks system is almost 168 times that of hydrothermal systems [2,4].

The development of a geothermal resource requires the presence of a circulation fluid necessary to extract the heat from the reservoir to the surface. This involves a non-isothermal flow because of heat exchange [2]. Subsurface heat transfer can occur in conductive and convective heat transfer modes. Besides these, other prevalent uncertainties affect the distribution and transfer of heat. These factors could be reservoir-resident factors such as reservoir heterogeneities and geological structures and factors from the well layout and designs such as doublet conditions [2]. An accurate understanding of heat flow which enables proper estimation of heat production is necessary to maximize heat production from the subsurface [5].

The electricity producible from geothermal resources depends fundamentally on the nature of underground resource conditions. Although geological assessment of in-situ thermal resources is available but the more reliable resource assessments are guaranteed after test wells are drilled to the subsurface. Electricity is produced from geothermal fluids using suitable Rankine cycle power plants. Three types of power plants are used for electricity generation from geothermal energy; these are the dry steam plants, the flash cycle plants, and the binary cycle plants [6]. The dry steam geothermal power plants are used for electricity generation when the geothermal resource produces hot dry steam directly from the well. The steam comes from the well and is first passed through separators that remove sands and rock particles before it is sent to the turbine. Flash steam plants are utilized on occasions where the geothermal resource produces high-temperature hot water or a combination of steam and hot water. The fluid from the well is delivered to a flash tank where a portion of the water flashes to steam and is directed to the turbine. Two-stage flash tanks could be utilized depending on the temperature of the fluids. They are the most common types of geothermal power plants due to the lack of naturally occurring high-quality steam. But just like the former, his type of plant cannot be applied to low-temperature resources [6]. Binary geothermal power plants use a second fluid in a closed cycle to operate the turbine rather than geothermal steam. Binary power plants use fluids with low boiling points such as butane or pentane in a secondary loop. The water flowing from the well through a heat exchange transfers its heat to this fluid which causes vaporization of these fluids due to their low boiling point. It is then passed through a turbine and used for electricity generation [7-8].

There is evidence that supports the high initial cost of geothermal reservoirs when new fields are to be developed especially for geothermal resource extraction. This cost is mostly related to exploration and reservoir mappings present high upfront risk which may limit investment opportunities in geothermal resource extractions [9-10]. Because of this, suggestions have been made on the usage of abandoned oil and gas wells for geothermal resource extraction. These wells can be retrofitted for geothermal utilization. These wells were abandoned because petroleum recoveries from them were far below the marginal economic index. Although abandoned oil and gas wells can be used for geothermal extraction after being retrofitted with insulated production tubing, more attention is given to the usage of gas wells for this purpose. By retrofitting already existing wells for geothermal usage, initial investment costs from drilling and partially from completions would be obviated. Studies showed that abandoned oil and gas wells were beneficial to geothermal energy extraction [11-13].

2. Geothermal energy

Geothermal energy represents the thermal energy that comes from the earth due to the temperature of the hot reservoir rock. This heat comes from the core of the earth and is transferred from the core largely through conduction through solid rock, and then through convection in places with fluid contact (e.g. water, magma, salt diaper) [14]. There is enormous energy present in the earth's crust that can be harnessed for future energy needs. The overall thermal energy in this earth is in the range of 12.6 x 10^{12} EJ and 5.4 x 10^9 EJ in the range of crust up to a depth of 50 km [15].

There has been an existence of geothermal energy residents in Nigeria's geographical location. Most of the geothermal resources in Nigeria come as warm/hot springs, seepages located mainly within the sedimentary basin of Benue Trough. The geothermal resources in Nigeria include the Ikogosi warm spring with a temperature of 37°C [16]. Rafin Reewa, is another warm spring in Jos Plateau with a temperature of 42°C and runs from. There have been shreds of evidence suggesting the existence of geothermal resources in the Anambra basin, Sokoto basin, Chad basin, Bida basin.

3. Methodology

This section presents the methods for the study. This comprises the development of models for geothermal systems and the simulation of the model in computer software.

3.1. Development of the models

This comprises the development of equations that governs the system and all processes involved. For this work, the equation development shall comprise three distinct parts, they are

1. Estimation of geothermal heat resource
2. Modeling the heat flow rate in the extraction wells
3. Electrical power calculation using turbines

3.1.1. Estimation of geothermal heat resource

The type of geothermal reserve determines the equation for the estimation of its heat capacity. The geothermal reservoir may contain dry steam, wet steam, dry rock as its source of heat. These have their peculiar models used in the estimation of the resident heat at reservoir conditions.

The heat transfer medium used in this research work is wet steam which comprises steam and hot water. The determination of the heat potential is therefore done for hot water and steam. The total heat in the reservoir is the sum of the heat of the two phases co-existing together in the reservoir.

The thermal energy from hot water in a geothermal reservoir is given below as

$$E_{iw} = \phi_i \rho_w C_w V_i (T_i - T_o) \quad (1)$$

where C_{wi} is the volumetric heat capacity of the hot water for ith volume; ρ_{fi} is the density of the hot water for the ith volume.

Similarly, if the fluid in the reservoir contains hot water and steam, then a two-phase system co-exist and the overall fluids thermal energy is given as

$$E_{if} = \phi_i \rho_w C_w V_i (T_i - T_o) + \phi_i \rho_s C_s V_i (T_i - T_o) \quad (2)$$

where C_{si} is the volumetric heat capacity of the steam for ith volume; ρ_{si} is the density of the steam for the ith volume.

There are some systems where the heat sources are a combination of rock and fluid energy. In this system, thermal energy is a contribution of the heat from the rock and the fluid. The thermal energy for this reservoir system is estimated below

$$E_i = E_{ir} + E_{if} \quad (3)$$

This can further be expanded to become

$$E_i = (1 - \phi_i) \rho_{ri} C_{ri} V_i (T_i - T_o) + \phi_i \rho_w C_w V_i (T_i - T_o) \quad (4)$$

To calculate the energy in the whole reservoir, integration of the entire reservoir is done. If the reservoir is composed of n volume components, then the total thermal energy in the reservoir is given as

$$E_R = \int_i^n \mathrm{E_i} dv \quad (5)$$

Note that

$$\mathrm{V} = \mathrm{V_i} + \mathrm{V_k} + - - - \mathrm{V_n} \quad (6)$$

Not all the thermal energy in the reservoir is recoverable. The amount of heat recoverable is a function of the extraction technology and method of extraction applied. The recovery factor is the ratio of the total thermal energy recoverable from the reservoir to the total thermal energy in place in the reservoir at initial conditions. The recovery factor is given as R

$$R = \frac{E_S}{E_R} \quad (7)$$

E_s is the thermal resource extractable at the current technological and economic condition; E_R is the total thermal resource in the reservoir.

$$E_s = E_R n \quad (8)$$

3.1.2. Modeling the heat flow in the extraction wells

The energy exchange equations which fundamentally comprises the thermal variations and heat transfers along with the extraction well for wet-steam dominated geothermal reservoirs is given in this section

The equation for energy in the extraction fluid well is given in equation 9

$$\frac{\mathrm{dT_{ex}}}{\mathrm{dt}} + \frac{\mathrm{d(VT_{ex})}}{\mathrm{dz}} = -\mathrm{S_{exin}} \quad (9)$$

where Tex fluid temperature in extraction well; V fluid flowrate; z vertical distance from earth surface; t time interval; S_{exin} heat exchange rate between extraction well.

$$\mathrm{S_{inex}} = \frac{\mathrm{k_l(T_{in} - T_{ex})}}{\mathrm{\rho A_{ex} C_p}} \quad (10)$$

where ρ density of the fluid; A_{ex} Flow area of the extraction well; C_p Specific heat of the fluid in the extraction well; k_l heat conductivity coefficient for unit length.

$$\mathrm{A_{ex}} = \pi \mathrm{r_{ex}^2} \quad (11)$$

where r_{ex} the radius of the reservoir.

3.1.3. Electrical power calculation using turbines

This section deals with the calculations involved in the conversion of the thermal energy in the geo-fluid to electrical power using turbine systems. Two major types of turbines are useful with a geo-fluid in production of electricity: they are the flash turbine system and the binary turbine system

i.) Installed power

The Installed power gotten from a geothermal plant due to thermal energy from a geothermal resource is given as

$$\mathrm{P_i} = \frac{\mathrm{E_R C_e}}{\mathrm{f_l t}} \quad (12)$$

where E_R is recoverable heat, KJ; P_i is installed power,MWe; C_e is conversion efficiency of plant; f_l is load factor; t is commercial lifespan of the plant, Msec.

ii.) Flash system turbine calculation

Because the geothermal resource utilized in this study is fluid dominated saturated steam system, a flash turbine system would be the most appropriate turbine type for use in the generation of electricity using the geo-fluid

Figure 1 illustrates the temperature-entropy diagram of a single flash turbine system.

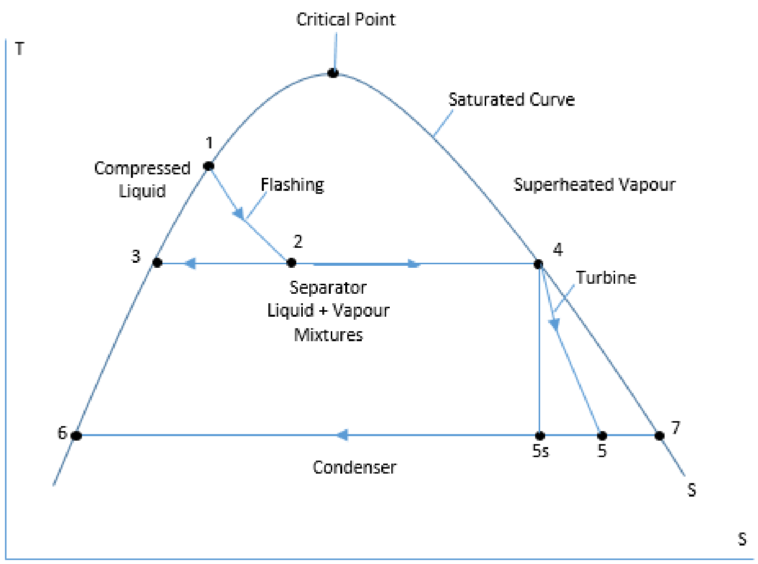

Figure 1. Temperature-Entropy diagram for single flash turbine system for geothermal heat conversion to electricity

The single flash turbine system comprises several processes; these include the flashing process, the separation process, the expansion process, and the condensation process. The block diagram in Figure 2 illustrates the sequences in the single flash turbine process.

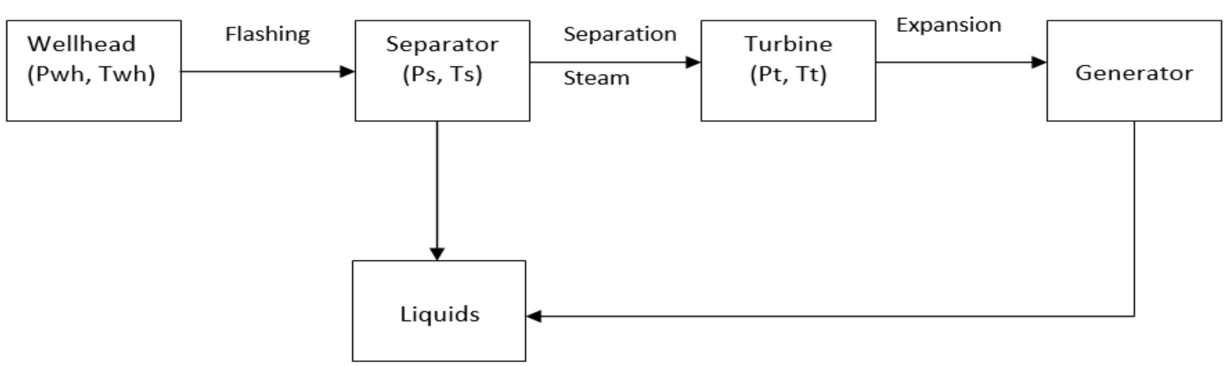

Figure 2. Block diagram of single flash process

The electrical power output of the flash turbine system can be given from Figure 2 as

$$w_e = x_2 m_{total}(h_4 - h_{5s})\eta_t\eta_g \quad (13)$$

where m_{total} is total flowrate of the mixture of vapor and hot water at point 2; η_g is generator efficiency; η_t is isentropic efficiency of the turbine; x_2 is ratio of steam to liquid.

$$x_2 = \frac{h_2 - h_3}{h_4 - h_3} \quad (14)$$

3.2. Case study

The case study used in this work is four oil and gas wells in field Asa-2 in the Niger Delta. The wells are wells AX-2, AX-3, AX-5 and AX-7. These are abandoned oil and gas wells that have been converted to geothermal wells and used for heat extraction. This was chosen to reduce the cost of exploration and drilling that would be associated with developing a new geothermal well that was not previously drilled. Using an abandoned oil and gas well limits the economic expenses in terms of exploration, drilling, and well completion. Except that the well has to be retrofitted to accommodate the high-temperature fluid recovery. An insulated

production liner will be used. By this, the total cost of producing a unit of electricity from the geothermal reservoir would be greatly decreased.
The reservoir data and the fluid data at the wellhead and surface equipment respectively as well as the parameters for the turbine system used are given below in tables 1 and 2. The properties of each well are given in table 3

Table 1. Geothermal reservoir parameters

Parameter	Units
Fluid Reservoir temperature, °C	170 °C (338 °F)
Reservoir Pressure, psia	4300
Fluid temp @wellhead, °C	197.2
Fluid pressure @ wellhead, bar	227.91 psia
Porosity	0.25
Permeability, mD	600
Area of Reservoir, acres	100
Reservoir thickness, ft	200
Density of steam in reservoir, kg/m^3	11.57
Density of hot water, kg/m3	960
Heat capacity of hot water, kJ/kg.K	4.2
Heat capacity of steam, kJ/kg.K	3.408
Environmental temperature, °C	30

Table 2. Fluid parameters

Points	Enthalpy, kJ/kg	Entropy, kJ/kg.K
1	839.9	2.203
2	839.9	2.203
3	482.5	1.463
4	269.9	7.1842
5	2356.7	-
5s	2271.16	7.1842
6	-	0.6387
7	-	8.1648

Table 3. Properties of each well

Parameter	Well Values			
	Well AX-2	Well AX-3	Well AX-5	Well AX-7
wellhead pressure, psig	200	200	200	200
wellhead temperature, °C	197.2	206	177.7	171.4
skin	3	3.5	4	3.7
tubing size, in	3.958	3.958	3.958	3.958
well radius, ft	0.56	0.56	0.56	0.56
geothermal gradient, °F/100ft	4.17	4.39	3.68	3.53
well depth, ft	9890	10100	11,200	11,800

3.3. Construction of the geothermal field production

GAP was used to construct the field geothermal wells resource production. There are a total of four wells that were previously used for oil and gas production. The wells were converted and used for geothermal heat extraction. The flow diagram of the extraction wells is given in the Figure 3.

All the fluids are extracted from one reservoir. Each of the fluids flow to the wellheads. All the wellhead fluids are channeled to the production manifold where they are then routed to the separator. Flash takes place between the wellheads and the separator.

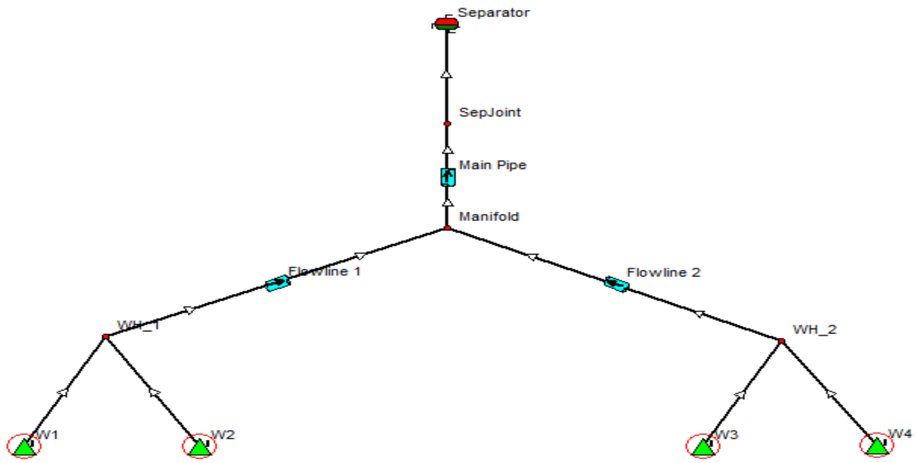

Figure 3: Well and surface lines arrangement

3.4. Simulation approach

The simulation was done by building models in MATLAB. This is done by writing Matlab scripts files that do essentially three basic things.

a. Estimates the recoverable heat in the reservoir given the geothermal system type
b. Estimates the wellbore heat loss from the reservoir to the surface given the wellbore and surface equipment used
c. Calculate the gross electrical power from the recovered heat

The block diagram of the modeling sequence is given in the Figure 4.

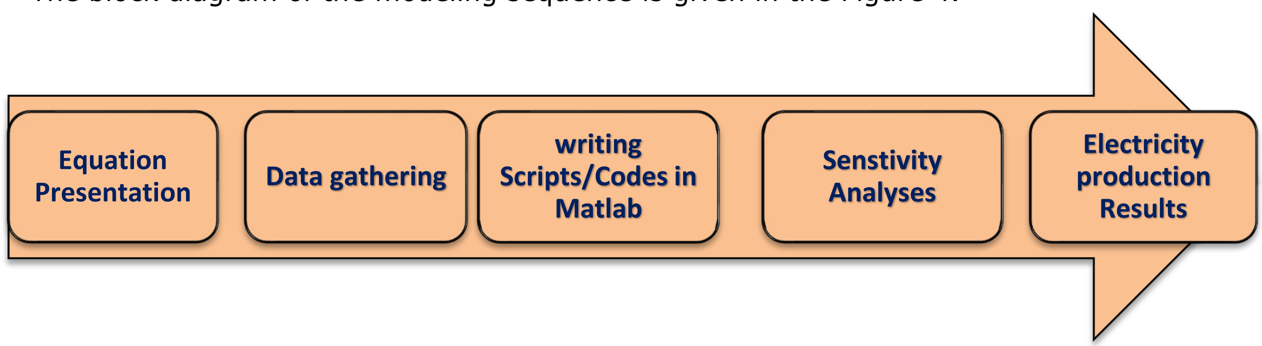

Figure 4. Block diagram of methodological procedure

3.5. Well model

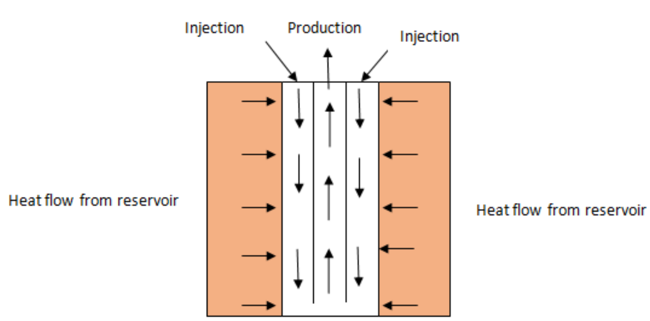

Figure 5. Schematic diagram of the modeled geothermal system

After the wells were abandoned, before plugging the wells, they were converted to geothermal wells. This was done through retrofitting and the addition of insulators at the casing to prevent heat losses from the reservoir to the surface. The insulation was achieved by sealing off the bottom of the casing with non-conductive materials. A schematic diagram of the model is given in Figure 5. Figure 6 shows the vertical section of the geothermal well. It can be observed that the well was completed with 9 5/8 in casing.

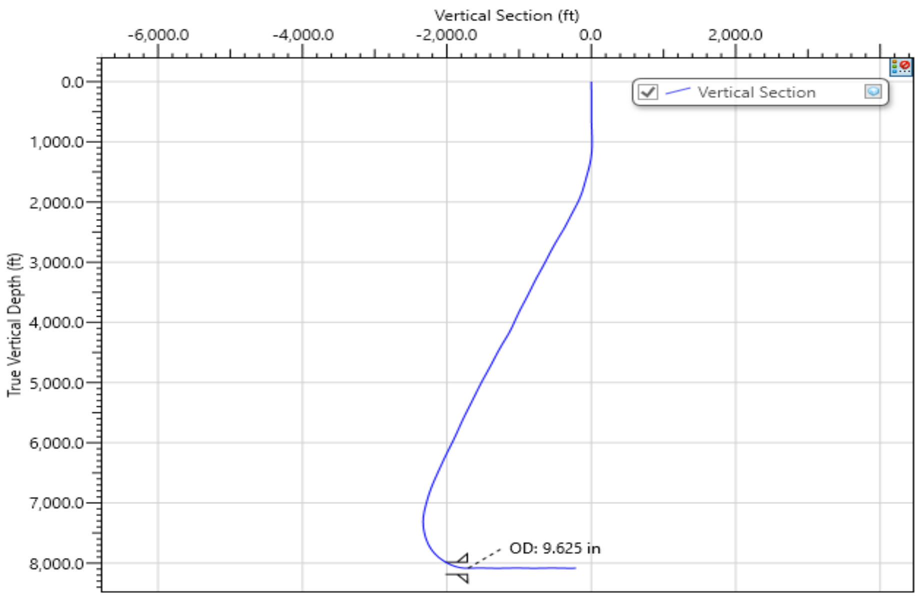

Figure 6. Vertical profile of the well AX-2

4. Results and discussions

4.1. Geothermal resource potential

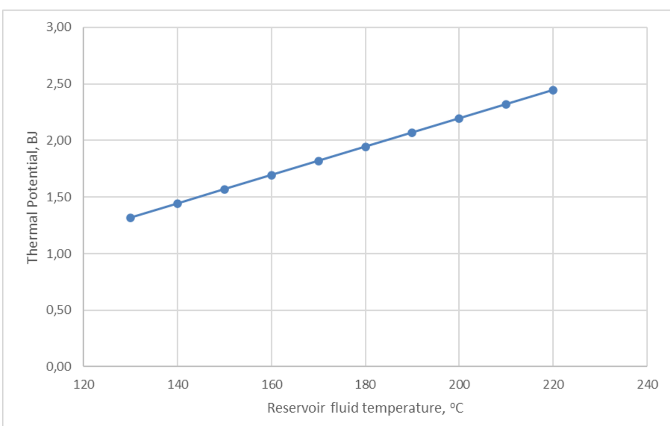

Figure 7. Thermal potential as a function of reservoir temperature

The Geothermal heat resource potential from the simulation performed is 2.45 x 10^{12} Joules. This was determined using equation 4 and 5 .But not all of this heat can be extracted. The heat potential as a function of reservoir temperature is given in the Figure 7. From Figure 7, it can be observed that the geothermal heat potential of a geothermal reservoir increases with an increase in reservoir temperature. As the wet steam is produced, the pressure of the reservoir begins to decrease.

4.2. Specific gross electrical energy per molar flow rate of steam

The specific gross electrical power from the turbine from each of the four wells corresponding to their various wellhead fluid temperatures is given in this section. The specific gross electrical power is the gross electrical power per mass flowrate of steam from each wellhead for the four wells considered. The flash turbine system simulated produced gross electrical power per mass flowrate of steam for various separator temperatures and condenser (sink) temperatures.

a) Well 1: Wellhead fluid temperature of 167°C

The specific gross electrical power is given in the Table 4 for well 1

Table 4. Well 1 Specific gross electrical power output

Separator temperature, °C	Specific gross electrical power, kW/(kg/s)			
	Sink Temp= 45°C	Sink Temp= 50°C	Sink Temp= 55°C	Sink Temp= 60°C
95	44.39	39.76	35.17	30.63
100	46.13	41.73	37.38	33.07
105	47.36	43.20	39.07	35.00
110	48.27	44.34	40.43	36.58
115	48.67	44.96	41.29	37.66
120	48.74	45.25	41.81	38.39
125	48.32	45.06	41.85	38.66
130	47.58	44.55	41.55	38.59
135	46.38	43.57	40.80	37.61
140	44.84	42.27	39.71	37.18
145	42.88	40.52	38.18	35.88
150	40.58	38.45	36.33	34.24

The specific gross electrical power output for well 1 is given in Table 4. This is done for several separators and sinks temperatures. The shaded areas in Table 4 correspond to the maximum power output for the conditions specified. For sink temperatures of 45°C and 50°C, the maximum electrical power was 48.74 kJ/kg/s and 45.25 kJ/kg/s at a separator temperature of 120°C. But for sink temperatures of 55°C and 60°C, the maximum electrical power was 41.85 kJ/kg/s and 38.66kJ/kg/s at separator temperature 125°C

It can be observed from Table 4 that the specific gross electrical power produced increased with an increase in separator temperature for all condensers (sink temperatures) to a maximum point wherein it starts to decline. This point is the optimum operating condition of the turbine and must be determined for all turbine systems using geofluids.

b) Well 2: Wellhead fluid temperature of 165.5°C

The specific gross electrical output per mass flowrate of steam for well 2 is given in the Table 5

Table 5. Well 2 electrical power output

Separator temperature, °C	Specific gross electrical power, kW/(kg/s)			
	Sink Temp= 45°C	Sink Temp= 50°C	Sink Temp= 55°C	Sink Temp= 60°C
110	53.28	48.93	44.64	40.39
115	54.02	49.90	45.83	41.81
120	54.43	50.54	46.70	42.89
125	54.35	50.69	47.07	43.49
130	53.95	50.51	47.12	43.76
135	53.08	49.86	46.69	43.54
140	51.88	48.89	45.93	43.01
145	50.23	47.47	44.73	42.03
150	48.27	45.72	43.21	40.72
155	45.85	43.54	41.24	38.97
160	43.13	41.02	38.96	36.90
165	39.96	38.09	36.24	34.41

This is done for several separators and sink temperatures. The shaded areas in the table correspond to the maximum power output for the conditions specified. For sink temperatures of 45°C and 50°C, the maximum electrical powers were 54.43 kJ/kg/s and 50.54 kJ/kg/s at a separator temperature of 120°C. But for sink temperatures of 55°C and 60°C, the maximum electrical power was 47.12kJ/kg/s and 43.76 kJ/kg/s at separator temperature 125°C.

Well 3: Wellhead fluid temperature of 164.7°C

The specific gross electrical power for well 3 is given in Table 6 for several separator and condenser (sink) temperatures.

Table 6. Well 3 electrical power output

Separator temperature, °C	Specific gross electrical power, kW/(kg/s)			
	Sink Temp= 45°C	Sink Temp= 50°C	Sink Temp= 55°C	Sink Temp= 60°C
95	35.67	31.95	28.26	24.62
100	36.61	33.12	29.52	26.24
105	37.08	33.82	30.59	27.40
110	37.20	34.17	31.16	28.19
115	36.85	34.04	31.26	28.52
120	36.15	33.57	31.02	28.49
125	35.01	32.64	30.31	28.01
130	33.52	31.38	29.26	27.19
135	31.59	29.67	27.78	25.92
140	29.32	27.64	25.97	24.31
145	26.65	25.18	23.73	22.30
150	23.63	22.38	21.15	19.93

This is done for several separators and sink temperatures. The shaded areas in the Table correspond to the maximum power output for the conditions specified. For sink temperatures of 45°C and 50°C, the maximum electrical powers were 37.20 kJ/kg/s and 34.17 kJ/kg/s at a separator temperature of 110°C. But for sink temperature of 55°C and 60°C, the maximum electrical power was 31.26 kJ/kg/s and 28.52 kJ/kg/s at separator temperature 115°C

c) Well 4: Wellhead fluid temperature of 161.4°C

Table 7: Well 4 electrical power output

Separator temperature, °C	Specific Gross Electrical Power, kW/(kg/s)			
	Sink Temp= 45°C	Sink Temp= 50°C	Sink Temp= 55°C	Sink Temp= 60°C
90	31.78	28.11	24.48	20.88
95	32.89	29.46	26.06	22.70
100	33.57	30.38	27.20	24.07
105	33.80	30.82	27.88	24.97
110	33.67	30.93	28.20	25.52
115	33.08	30.56	28.06	25.60
120	32.13	29.84	27.57	25.32
125	30.75	28.67	26.63	24.61
130	29.03	27.18	25.34	23.54
135	26.87	25.24	23.64	22.04
140	24.37	22.97	21.58	20.21
145	21.46	20.28	19.11	17.95

The electrical power output for well 4 is given in Table 7. This is done for several separators and sink temperatures. The shaded areas in Table 7 correspond to the maximum power output for the conditions specified. For sink temperature of 45°C, the maximum specific gross electrical power output was 33.80 kJ/kg/s at a separator temperature of 105°C; for sink temperature of 60°C and 50°C, the maximum specific electrical power output is 30.93 kJ/kg/s and 28.2 kJ/kg/s respectively all at separator temperature of 110°C. Similarly, for sink temperature of 60°C, the maximum specific gross electrical power output was 25.60 kJ/kg/s at a separator temperature of 115°C. At a given separator temperature, the electrical power out decreases as the condenser temperature increases (sink temperature).

4.3. Actual gross electrical power for steam flowrates

The gross electrical power for steam flowrates according to each well's capacity is given in Figure 8 for sink (condenser) temperature of 45°C. As can be observed from the plot, the gross electrical power output produced is highest for well 2(2.99 MW at 105°F) and lowest for well 4 (2.20 MW at 110 °F).

The gross electrical power for steam flowrates according to each well's capacity is given in Figure 9 for sink (condenser) temperature of 50°C. As can be observed from the plot, the gross electrical power output produced is highest for well 2 (2.79 MW at 110°F) and lowest for well 4 (2.01 MW at 115°F).

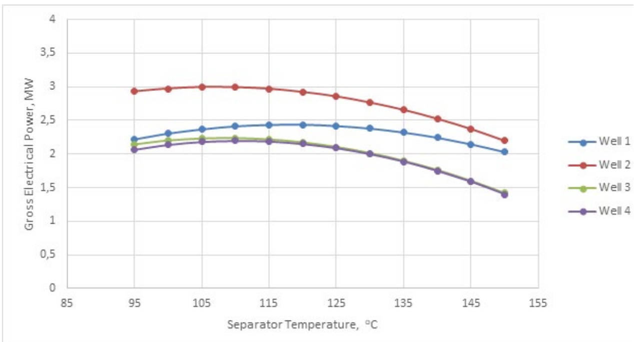

Figure 8. Gross electrical power output for several wells at 45°C sink temperature

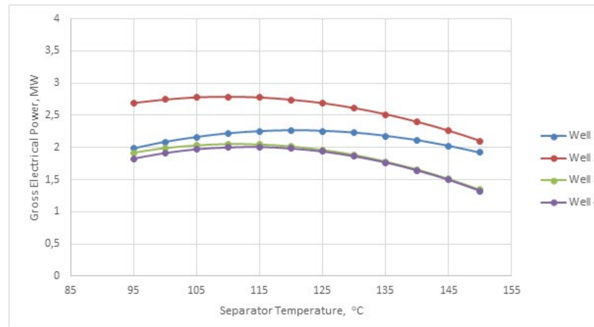

Figure 9. Gross electrical power output for several wells at 50°C sink temperature

The gross electrical power for steam flowrates according to each well's capacity is given in Figure 10 for sink (condenser) temperature of 55°C. As can be observed from the plot, the gross electrical power output produced is highest for well 2 (2.79 MW at 110°F) and lowest for well 4 (2.01 MW at 115°F).

The gross electrical power for steam flowrates according to each well's capacity is given in Figure 11 for sink (condenser) temperature of 60°C. As can be observed from the plot, the gross electrical power output produced is highest for well 2 (2.79 MW at 110 °F) and lowest for well 4 (2.01 MW at 115°F).

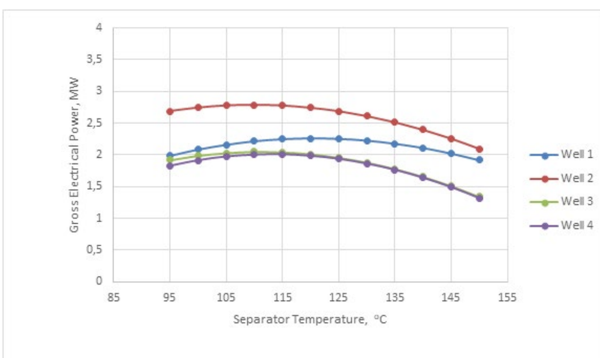

Figure 10. Gross electrical Power output for several wells at 55°C sink temperature

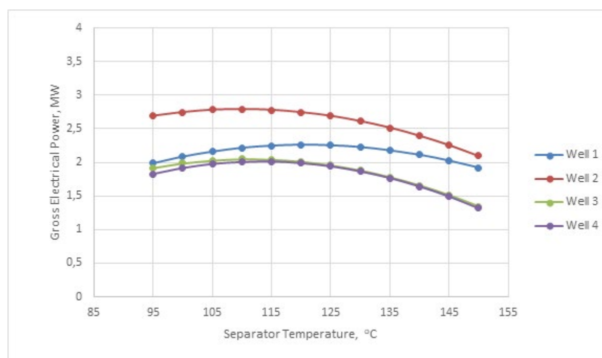

Figure 11. Gross electrical Power output for several wells at 60°C sink temperature

4.4. Discussion of result

Comprehensive simulation of the geothermal potential in the development of geothermal reservoirs has been carried out. From section 3.1, the geothermal heat resource potential was given. This was calculated from equation (2) in chapter three because the source of heat for this work is steam and hot water at in-situ reservoir conditions. Because of this vapor-liquid-dominated geothermal system, a single flash turbine was used in electricity production. For each well, the wellhead pressure and temperature were given and these were used to determine the wellhead temperature corresponding to the saturated fluid from steam tables.

The electricity production was calculated in two stages. The first was done per unit mass of steam flow rate to get the specific gross electrical power output while the second gave the total electrical power produced as a result of each well's steam flowrate produced in the separator. The electrical power output was crucially determined by the temperature of the separator and the sink (condenser) and the flow rate of the steam flashed and separated in the separator.

Well 2 because of its high temperature gave the highest gross electrical power for all cases of sink pressures and separator pressure.

From the sensitivity analyses conducted using sink pressures; it was observed that the gross electrical power output decreased with an increase in sink temperatures. But for the case of separator pressure, the gross electrical power output initially increased with an increase in separator pressure until a maximum value is reached wherein the gross electrical power output begins to decrease with an increase in separator temperature.

5. Conclusions

Modeling of geothermal reservoir potential using depleted oil and gas wells has been conducted. The abandoned oil/gas well was necessary to offset investment costs in drilling and completion of new wells for geothermal resource exploitation thereby improving the economic feasibility of the project and the affordability of the electrical resource produced in the process.

The process was done to quantify the geothermal resource potential and possible electrical energy produced from the flowrate and pressure-temperature conditions of the wellhead saturated geofluids produced. A single flash turbine system was used and the electrical power produced was given unit of a mass flow rate of steam (kJ/kg/s) and in actual electrical power as a result of each well's steam flowrate produced (in MW). The geothermal resource was estimated as 2.45 x 10^{12} Joules. The optimum separator temperature obtained for the wells are 120°C, 120°C, 110°C, and 105°C for well 1, well 2, well 3, and well 4 respectively. The electrical power produced decreased with increasing sink temperature. Thus 45°C was the best sink temperature because it led to the highest electric power generation.

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