Geothermal Energy for Electricity Generation

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Abstract

A theoretical investigation of the electricity generation from geothermal energy has been established for different year months and earth's depths. The efficiency of Carnot cycle of the geothermal power plant increases with increasing temperature difference between the productions well and the re-injection well temperature. It is found that the largest value of temperature difference is at Jan. and Dec., and the lower value is at July. The largest value of electricity production for the geothermal power plant is at Jan. and Dec. and the lower value is at July. The largest value of heat supplied from geothermal power plant is at Jan. and Dec., and the lower value is at May. The increasing in earth's depth will increase the power production, and the largest value of power production is at Jan. and Dec. whereas the lower value is at Jun. and July.

Keywords: Geothermal; Geothermal Power Generation; Thermodynamic Efficiency; Electricity Generation; Rejection Temperature.

Introduction

Geothermal energy is the energy derived from the heat of the earth's core. It is clean, abundant, and reliable. If properly developed, it can offer a renewable and sustainable energy source. There are three primary applications of geothermal energy: electricity generation, direct use of heat, and ground-source heat pumps. Direct use include supplications such as heating buildings or greenhouses and drying foods, whereas ground source heat pumps are used to heat and cool buildings using surface soils as a heat reservoir. This paper covers the use of geothermal resources for production of utility scale electricity and provides an overview of the history of technologies.

Understanding geothermal energy begins with an understanding of the source of this energy - the earth's internal heat. The Earth's temperature increases with depth, with the temperature at the center reaching more than 4200 °C (7600 °F). A portion of this heat is a relic of the planet's formation about 4.5 billion years ago, and a portion is generated by the continuing decay of radioactive isotopes. Heat naturally moves from hotter to cooler regions, so Earth's heat flows from its interior toward the surface.

Because the geologic processes known as plate tectonics, the Earth's crust has been broken into 12 huge plates that move apart or push together at a rate of millimeters per year. Where two plates collide, one plate can thrust below the other, producing extraordinary phenomena such as ocean trenches or strong earthquakes. At great depth, just above the down going plate, temperatures become high enough to melt rock, forming magma. Because magma is less dense than surrounding rocks, it moves up toward the earth's crust and carries heat from below. Sometimes magma rises to the surface through thin or fractured crust as lava. However, most magma remains below earth's crust and heats the surrounding rocks and subterranean water. Some of this water comes all the way up to the surface through faults and cracks in the earth as hot springs or geysers. When this rising hot water and steam is trapped in permeable rocks under a layerofimpermeable rocks, it is called a geothermal reservoir. These reservoirs are sources of geothermal energy that can potentially be tapped for electricity generation or direct use [Masashi,2003].

Geothermal energy can be defined as heat that originates within the earth. This heat occurs from a combination of two sources: the original heat produced from the formation of the earth by gravitational collapse and the heat produced by the radioactive decay of various isotopes. Because the thermal conductivity of rock is so low, it is taking many billions of years for the earth to cool. Geothermal resources can be divided into four types: hydrothermal, geopressured, hot dry rock, and magma. Except for geothermal (or ground-source) heat pumps, which utilize the heat contained in shallow soil, all existing uses of geothermal energy make use of hydrothermal resources, which consist of some combination of hot water and steam located in permeable rock. The hot geothermal fluid is used for direct heating applications such as spas, green houses, district heating and the like. If the resource temperature is greater than about 90ºC, it can be utilized to generate electricity [Charles,2000].

Direct utilization of geothermal energy refers to the immediate use of the heat energy rather than to its conversion to electrical energy. The primary forms of direct use include heating and cooling. Geothermal energy could be used to supply hot water or could be used with a special equipment (radiators) to make buildings warmer during winter seasons. In general, the geothermal fluid temperatures required for direct heat use are lower than those for economic electric power generation. Most direct use applications use geothermal fluids in the low-to-moderate temperature range between50 and 150 C^o [Haytham,2000].
In this research, design calculations for the amount of heat supplied, power production and electricity generation from geothermal energy during the year months are carried out.

Design Calculations

Calculations of power for each month in one year based on the average temperatures are performed as shown in tables below the outlet temperature from well is $80C^o$and geothermal water delivery (D) is 5000 m3/day = 208333,33 kg/h.

Numerical Example for JANUARY [Ivo,2000]:

1. Total working hours = 31 days*24 h*β = 774 h*0.8
z ≈ 619 h

2. Temperature difference $\Delta t = 79.4C^o$ (from Table 2)

3. Heat supplied $Q = D*C_P*\Delta t$

Q = 208333.33*1/860*79.4

Q = 19234.5kWt

4. Carnot efficiency $\eta_C = \Delta T / Tmax = 79.4/(80+273)$

η_C =79.4/353= 0.2249 ≈ 22.5%

5. Power $P = Q*\eta_C$ = 19234.5*0.225

P = 4326.4kWe

6. Electricity production E = P*z = 4326.4*619

E = 2678.041 kWh
The same procedures were performed for other months.

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From figure (4) [www.bassfeld,2011] ,we deduce that all above calculations were taken for earth depth of 1500 m ,we can repeat the above calculations for depth of 500,1000,2000,2500,3000 meters and as listed in tables(1),(2),(3),(4) and (5).

Results and Discussion

Results were obtained for electricity generation from geothermal energy at different earth's depth and year months, as follows:

Fig.(1) represents the relationship between Carnot cycle efficiency for geothermal power plant with temperature difference(the difference between the production well and the re- injection well temperature) for the outlet temperature of the well of 80 C^o and earth's depth of 1500m.One can observe that increasing the temperature difference leads to increasing Carnot cycle efficiency.

Fig.(2) shows the temperature difference during the year months for 80 C^o of the outlet temperature of the well, and earth's depth of 1500m.The largest value of temperature difference is at Jan. an Dec., and the lower value of it at July.

Fig.(3) shows the electricity production from geothermal power during the year months for 80 C^o of the outlet temperature of the well, and earth's depth of 1500m.The largest value of electricity production is at Jan. and Dec., the lower value of it is at July.

Fig.(5)shows the heat supplied from the geothermal energy at the year months for 80 C^o of the outlet temperature of the well, and earth's depth of 1500m.The largest value of heat supplied at Jan. and Dec. ,and the lower value of it is at July..

Fig.(6) shows the relationship between geothermal power production and earth's depth for Jan.,Feb.,Mar.,Apr.,May., and Jun. , from which the increase in earth's depth will increase power production, the largest value of power production is at Jan. and the lower value of it is at Jun.

Fig.(7) show the relationship between geothermal power production and earth's depth for July,Aug.,Sep.,Oct.,Nov., and Dec. The increasing in earth's depth will increase power production. The largest value of power production is at Dec. and the lower value of it is at July.

Conclusions

The following conclusions can be obtained from the present work:

1. Carnot cycle efficiency of the geothermal power plant increases with increasing temperature difference between the electricity productions well and the re-injection well temperature.
2. The largest value of temperature difference is at Jan. and Dec. whereas the lower value is at July.
3. The largest value of electricity production for the geothermal power plant is at Jan. and Dec., and the lower value is at July.
4. The largest value of heat supplied from geothermal power is at Jan. and Dec. and the lower value is at May.
5. The increasing in earth's depth will increase the power production, and the largest value of power production is at Jan. and Dec, and the lower value is at Jun. and July.

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Nomenclature

t_o Re-injected Well Temperature (C^o)

C_p Heat Capacity (kj/kg.k^o)

β Capacity Factor (dimensionless figure)

Table (1) Geothermal Carnot cycle efficiency, heat supplied and power generation for 500m earth's depth (outlet temperature from well is 40 C^o)

Month	t_o (C^o)	Δt (C^o)	η_c %	Q (kWt)	P (kWe)
Jan.	0.6	39.4	12.5	9545	1193
Feb.	1.9	38.1	12.1	9229	1116
Mar.	5.3	34.7	1108	8406	931
Apr.	9.4	30.6	9.7	7431	719
May	19	21	6.7	5087	340
Jun.	21.6	18.4	5.8	4457	258
July	23.7	16.3	5.2	3948	205
Aug.	22.9	17.1	5.4	4142	223
Sep.	18.5	21.5	6.8	5208	354
Oct..	9.7	30.3	9.6	7340	704
Nov.	3.9	36.1	11.5	8745	1005
Dec.	1.2	38.8	12.3	9399	1156

Table (2) Geothermal Carnot cycle efficiency, heat supplied and power generation for 1000m earth's depth (outlet temperature from well is 60 C^o)

Month	t_o (C^o)	Δt (C^o)	η_c %	Q (kWt)	P (kWe)
Jan.	0.6	59.4	17.8	14389	2561
Feb.	1.9	58.1	17.4	14074	2448
Mar.	5.3	54.7	16.4	13250	2173
Apr.	9.4	50.6	15.4	12257	1850
May	19	41	12.3	9932	1221
Jun.	21.6	38.4	11.5	9302	1069
July	23.7	36.3	10.9	8793	958
Aug.	22.9	37.1	11.1	8987	997
Sep.	18.5	41.5	12.4	10053	1246
Oct..	9.7	50.3	15.1	12185	1839
Nov.	3.9	56.1	16.8	13590	2283
Dec.	1.2	58.8	17.6	14244	2506

Table (3) Geothermal Carnot cycle efficiency, heat supplied and power generation for 2000m earth's depth (outlet temperature from well is 100 C^o)

Month	t_o (C^o)	Δt (C^o)	η_c %	Q (kWt)	P (kWe)
Jan.	0.6	99.4	26.6	24079	6405
Feb.	1.9	98.1	26.3	23764	6249
Mar.	5.3	94.7	25.3	22940	5803
Apr.	9.4	90.6	24.2	21947	5311
May	19	81	21.7	19622	4257
Jun.	21.6	78.4	21	18992	3988
July	23.7	76.3	20.4	18483	3770
Aug.	22.9	77.1	20.6	18677	3847
Sep.	18.5	81.5	21.8	19743	4303
Oct..	9.7	90.3	24.2	21874	5293
Nov.	3.9	96.1	25.7	23280	5982
Dec.	1.2	98.8	26.4	239340	6385

Table (4) Geothermal Carnot cycle efficiency, heat supplied and power generation for 2500m earth's depth(outlet temperature from well is 120 C^o)

Month	t_o (C^o)	Δt (C^o)	η_c %	Q (kWt)	P (kWe)
Jan.	0.6	119.1	30.3	28851	8741
Feb.	1.9	118.1	30.05	28609	8597
Mar.	5.3	114.7	29.1	27785	8085
Apr.	9.4	110.6	28.1	26792	7528
May	19	101	25.7	24467	6288
Jun.	21.6	98.4	25	23837	5959
July	23.7	96.3	24.5	23328	5715
Aug.	22.9	97.1	24.7	23522	5809
Sep.	18.5	101.5	25.8	24588	6343
Oct..	9.7	110.3	28.06	26719	7497

Nov.	3.9	116.1	29.5	28124	8296
Dec.	1.2	118.8	30.2	28779	8691

Table (5) Geothermal Carnot cycle efficiency, heat supplied and power generation for 3000m earth's depth(outlet temperature from well is 140 C^o)

Month	t_o (C^o)	Δt (C^o)	η_c %	Q (kWt)	P (kWe)
Jan.	0.6	139.4	33.7	33769	11380
Feb.	1.9	138.1	33.4	33454	11173
Mar.	5.3	134.7	32.6	32630	10637
Apr.	9.4	130.6	31.6	31637	9972
May	19	121	29.2	29311	8558
Jun.	21.6	118.4	28.6	28682	8203
July	23.7	116.3	28.1	28173	7916
Aug.	22.9	117.1	28.3	28367	8027
Sep.	18.5	121.5	29.4	29311	8617
Oct..	9.7	130.3	31.5	31564	9942
Nov.	3.9	136.1	32.9	32969	10846
Dec.	1.2	138.8	33.6	33623	11297

Table (6) Heatsupplied, Power and Electricity generation

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.
Q(kWt)	19234	18920	18096	17102	13750	14147	13638	13832	14898	17030	15854	19089
P(kWe)	4326	4327	3818	3420	2198	2334	2168	2227	2592	3389	3408	4256
E(kWh)	2678.041	2678	2363	2117	1361	1445	1342	1378	1605	2098	2110	2635

Table (7) Data for the power calculation for the geothermal field [Haytham,2000**]**

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.
t_o C^o	0.6	1.9	5.3	9.4	19	21.6	23.7	22.9	18.5	9.7	3.9	1.2
Δt C^o	79.4	78.1	74.7	70.6	61	58.4	56.3	57.1	61.5	70.3	76.1	78.8
η_C % Carnot	22.5	22.1	21.1	20	17.3	16.5	15.9	16.1	17.4	19.9	21.5	22.3

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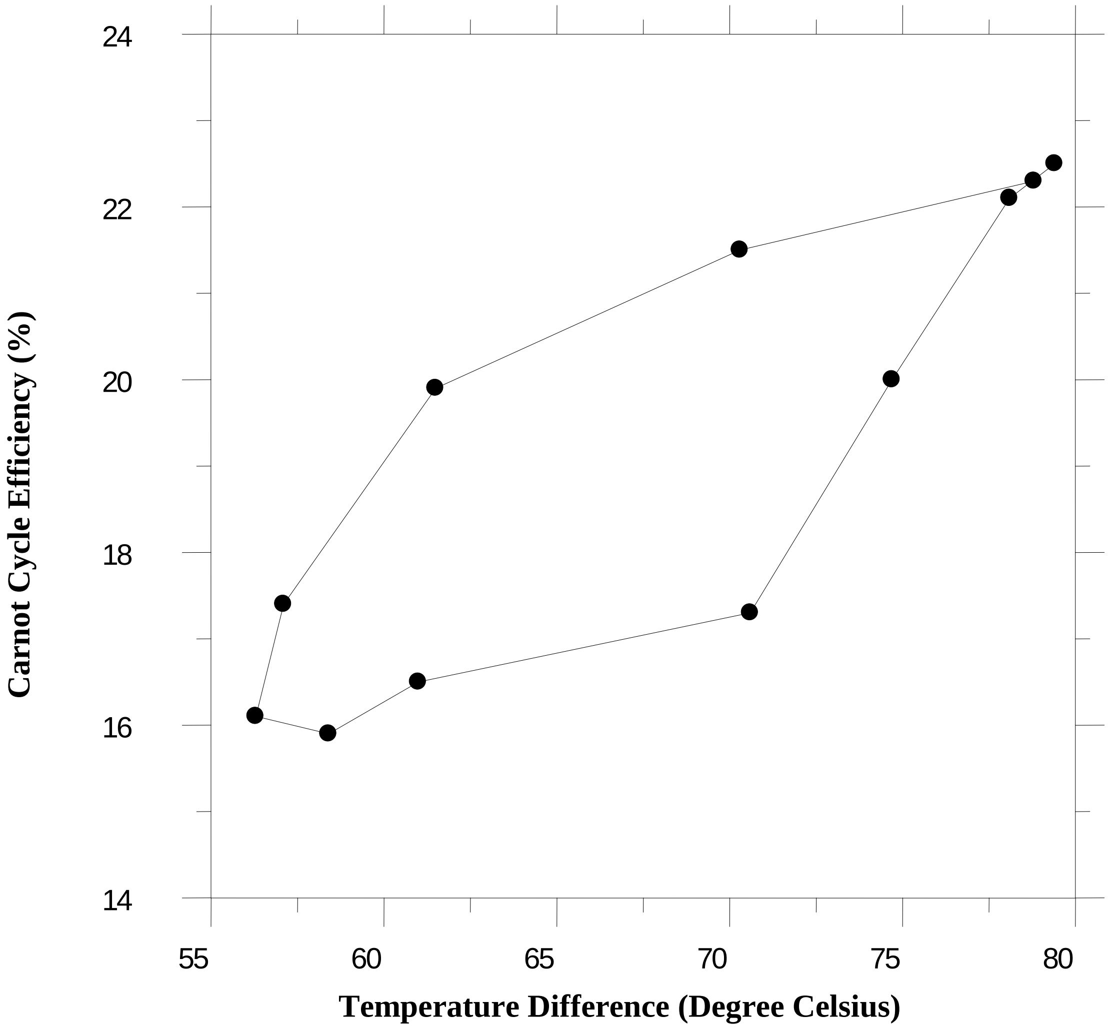

Figure (1) Variation of Carnot Cycle Efficiency with Geothermal Temperature Difference.

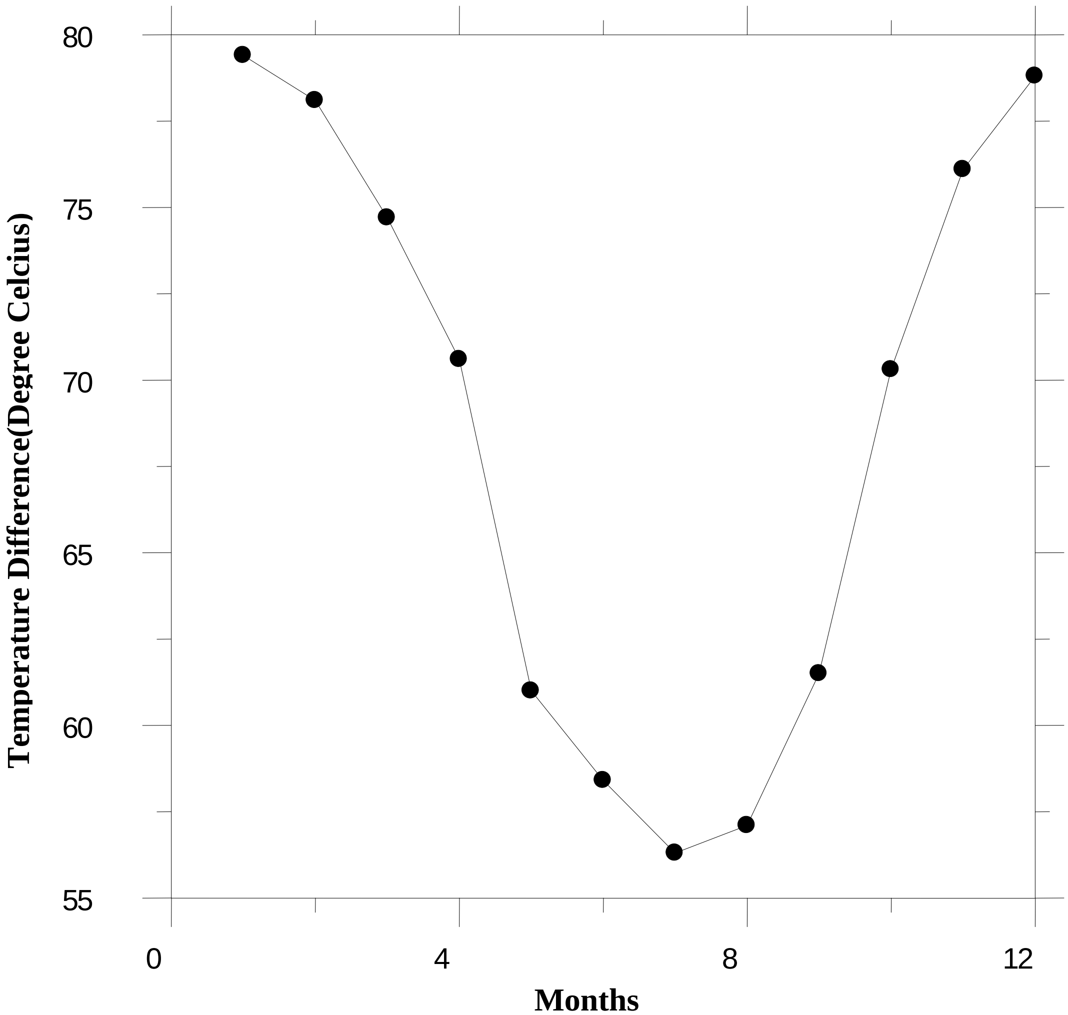

Figure (2) Variation of Geothermal Temperature Difference during the Year Months.

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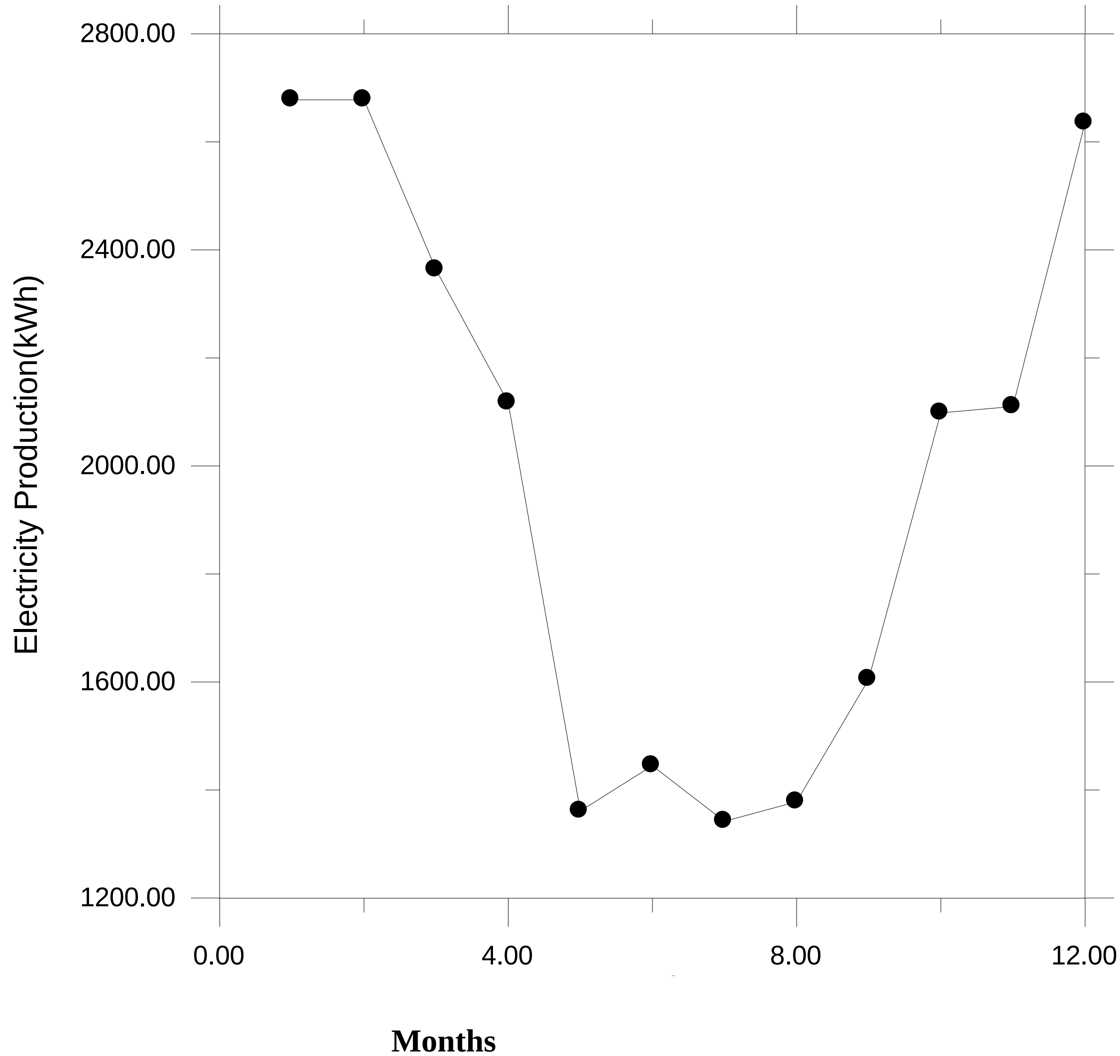

Figure(3) Variation of Electricity Production from Geothermal during the Months of Year.

Figure (3) Variation of Electricity Production from Geothermal Power during the Months of Year.

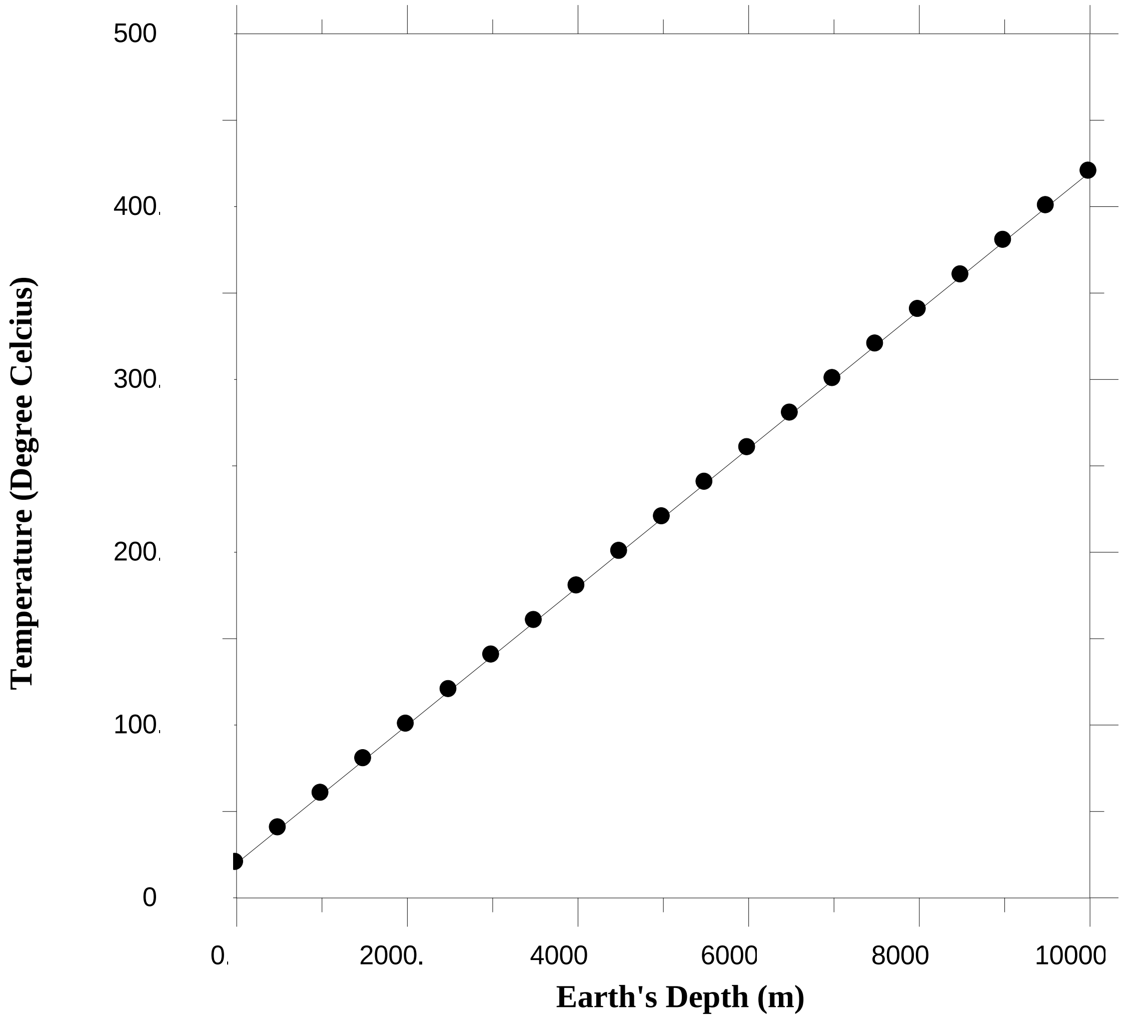

Figure (4) Variation of Temperature with Earth's Depth [Ivo, 2000].

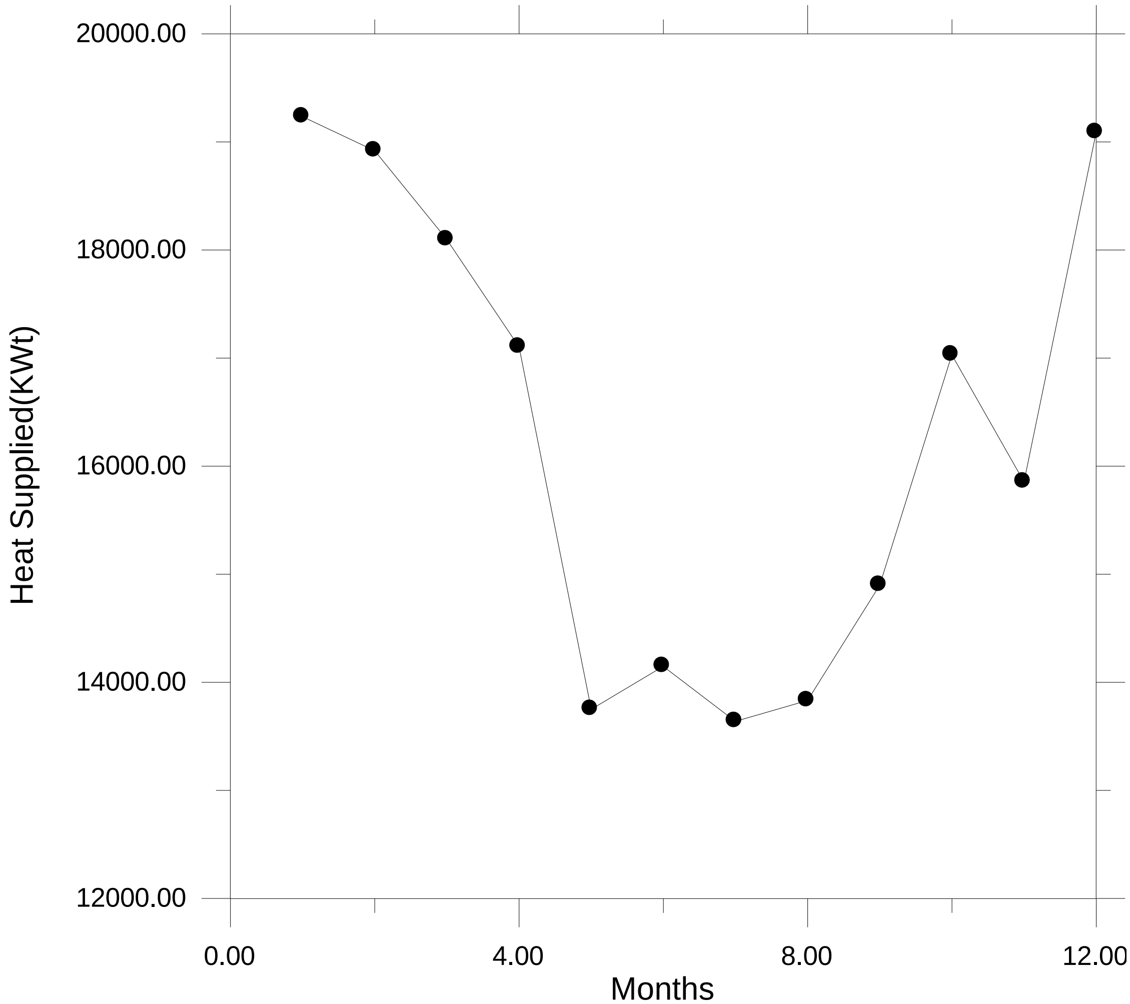

Figure (5) Variation of Heat Supplied from Geothermal Power during the Months of Years.

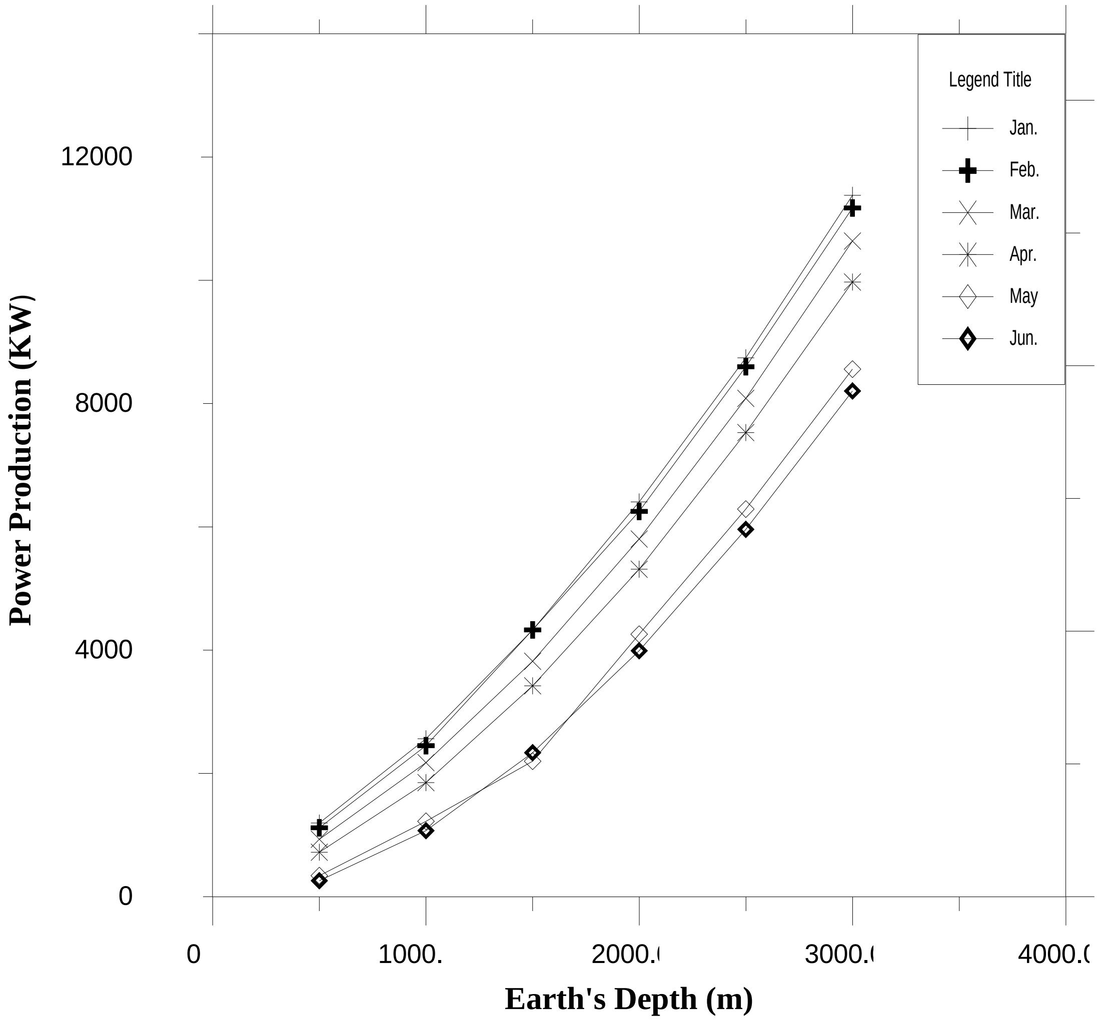

Figure (6) Variation of Power Production with Earth's Depth for July ,Aug, Sep.,Oct.,Nov. and Dec.

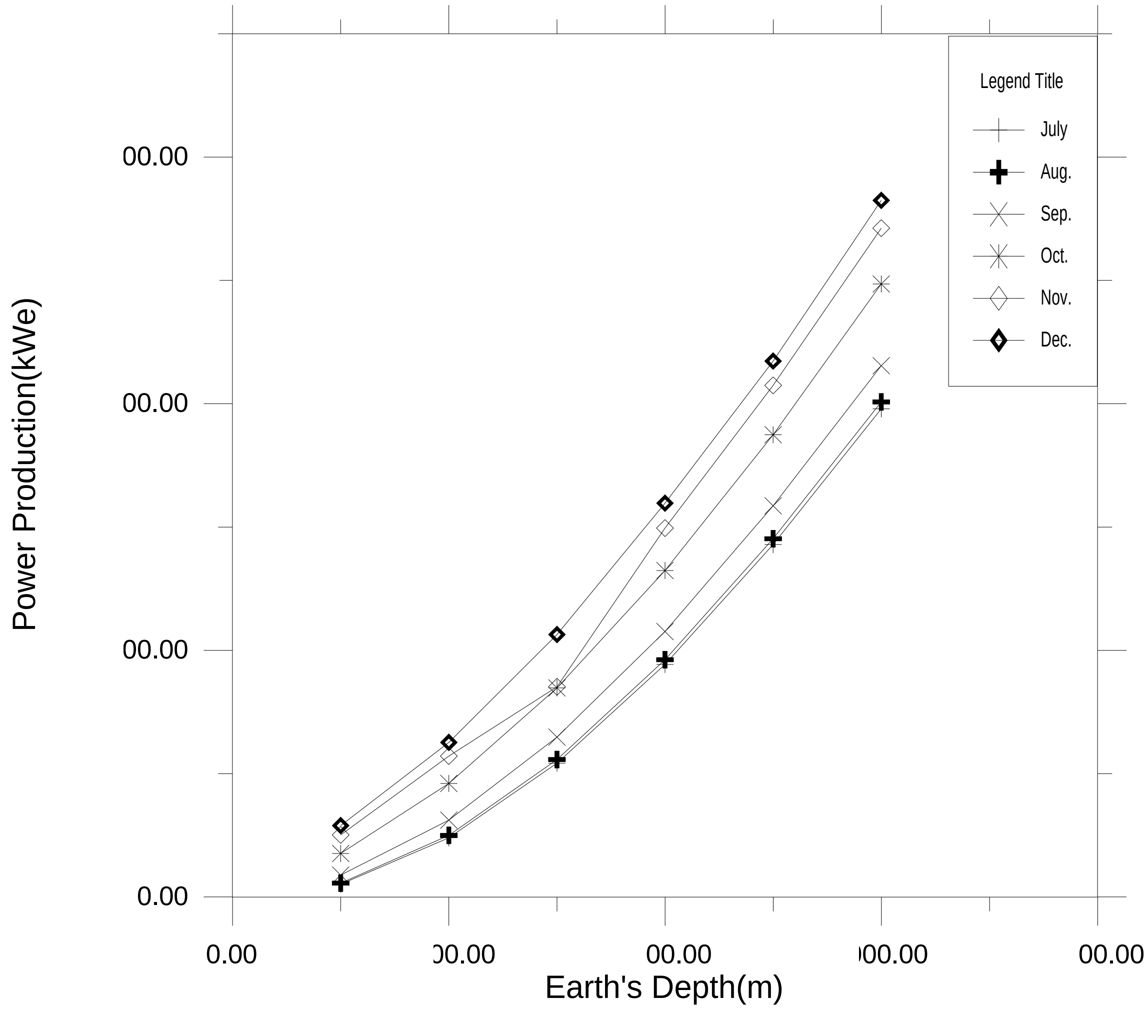

Figure (7) Variation of Power Production with Earth's Depth for July, Aug., Sep., Oct., Nov. and Dec.