

Original Research Article

ONE-DIMENSIONAL GEOTEMPERATURE MODELING USING ONE-LAYER MODEL FOR AWA OIL FIELD, NIGER DELTA SEDIMENTARY BASIN, NIGERIA USING ONE LAYER MODEL

ABSTRACT

In this research, one-dimensional steady state thermal structure in part of Niger Delta sedimentary basin has been modelled using one layer model. The solution to the Fourier one dimensional heat was used to generate geotherm with thermal conductivity, radiogenic heat production and boundary condition. The boundary conditions are surface temperature and heat flow of 27°C and 50mWm², The computed temperature using the model increases with depth from earth surface to about 6500 metres. Beyond 6500 metres, the temperature starts decreasing with depth as a result of the quadratic nature of the model. The depth range within which the temperature increases with depth falls within the Benin and Agbada Formations of the Niger Delta. Comparison between the computed temperature and measured bottom hole temperature from three wells reveal a very good matched. The difference between computed and measured temperature ranges between -4.0 to 6.0 °C. The thermal structure of the sedimentary basin is controlled by thermal conductivity and radiogenic heat production

Keywords: [Geotherm, Analytical modeling, Thermal conductivity, bottom hole temperature, Heat flow.]

1. INTRODUCTION

The earth is continuously losing heat to the atmosphere as a result of the earth's cooling and the decay of radioactive elements. The heat from the subsurface is responsible for mantle convection, plate tectonics, mountain building and thermal maturation of hydrocarbon [1]. Due to the important of geothermal status, considerable attention has been directed toward the study and understanding of the variation in the subsurface temperature field in space and time [2]. The primary observable quantity for heat flow is the temperature gradient, which is in turn is used to estimate the flow of heat from the earth's interior and hence draw inferences about the thermal structure and evolution of the subsurface.

The earth is made up of the core, mantle and crust. The earth crust is the topmost layer and it is solid in nature. The mantle lies in between the crust and the core and it is fluid in nature. The core which is the base of the earth interior is made up of the outer and inner cores. The inner core is solid while the outer core is fluid. Most heat in the earth is generated in the core and transported through the mantle and crust to the earth surface. The heat is usually transported by conduction, convection and radiation. Heat conduction is the major technique in the earth crust while convectional method is common in the mantle [3,].

Sedimentary basin lies on top of the earth crust and the temperature in the basin is control partly by activities beneath the basin. The temperature is the physical property which determine the direction of heat flow. The geotemperature usually increases with depth and

as a result heat flow from the earth's interior to the surface [4]. An understanding of the subsurface temperature can be used in detecting direction of fluid flow and subsurface pressure, determination of hydrocarbon source maturity and basin modelling. Temperature–depth profiles within the Earth are called geotherms. The aim of this work is to model one dimensional temperature equation for part of the Niger Delta sedimentary basin.

Figure 1 is a map of the Niger Delta showing the study area. The Niger Delta is the youngest sedimentary basin within the Benue Trough system and its development started after the Eocene tectonic phase [5 and 6]. The thickness of the Niger Delta sediment is about 12 Km and the main supplier of sediments are River Niger and River Benue.

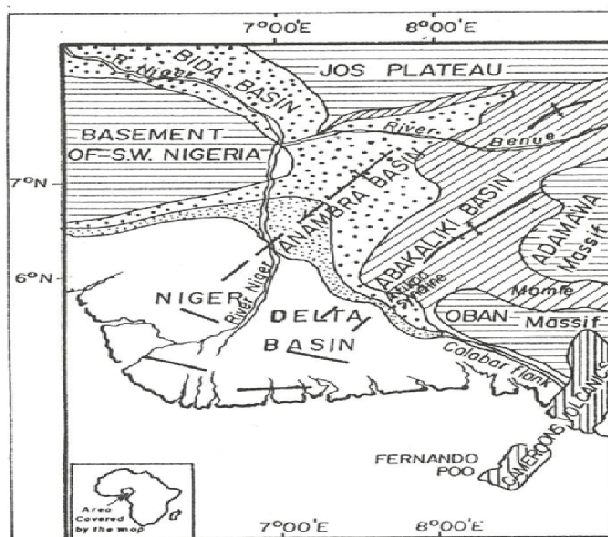
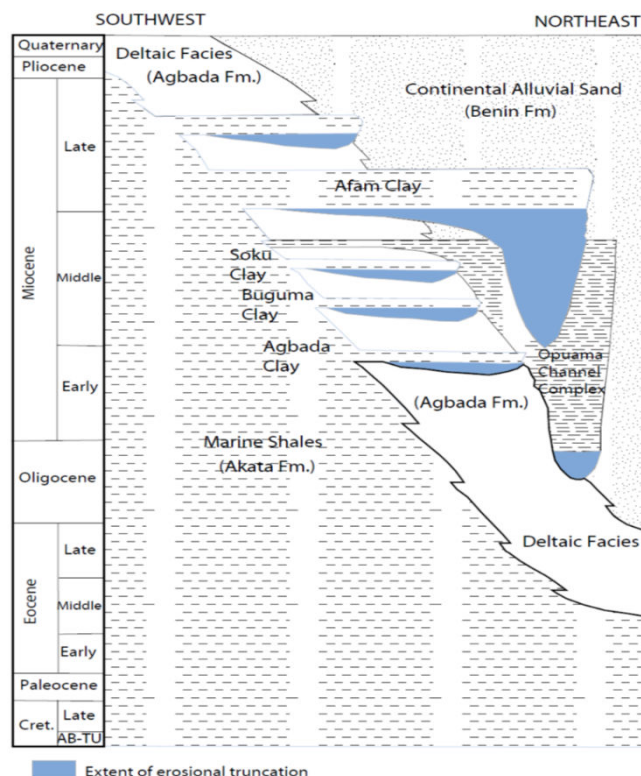


FIGURE1: MAP OF NIGERIA SHOWING NIGER DELTA AND STUDY AREA

The lithostratigraphy of the Niger Delta is divided into three Formations (Fig. 2.) representing prograding depositional facies that are distinguished based on sand – shale ratios. The Formations are Benin, Agbada and Akata Formations [7]. The Benin Formation is the youngest of the Delta sequence and it consists mainly of sand and gravels with thickness ranging from 0 – 2100 metres. The sands and sandstones in this Formation are coarse – fine, granular in texture and partly unconsolidated. The Benin Formation contains mainly feldspars, hemalites, lignite streak and limonite coatings. Little oil has been discovered in the Benin formation, and the formation is mainly water bearing. It is the major source of portable water in the Delta area [6].



55

56 Fig.2: Stratigraphic setting of Niger Delta showing the three formations of Niger Delta
57 [modified after 6]

58 The Agbada Formation consists of alternation of sandstones and shale and it lies beneath
59 the Benin Formation. The shale and sandstone were deposited in equal proportions in the
60 lower part of the formation. The deposition of Agbada Formation began in Eocene and
61 continues into Pleistocene. The thickness of the Agbada Formation ranges from 300m –
62 4500m (Short and it is the major host of Niger Delta hydrocarbon.

63 The Akata Formation forms the base of the transgressive Delta complex. It is of marine
64 origin and it consists of thick shale sequence (potential source rock), turbidite sand (potential
65 reservoir in deep water) and small amount of clay and silt [8]. The Akata Formation was
66 formed when terrestrial organic matter and clays were transported to deep water areas
67 characterized by low energy conditions and oxygen deficiency. The thickness ranges from 0
68 – 6000m. The Akata formation outcrops subsea in the outer Delta area but rarely seen
69 onshore. The formation outlies the entire Delta, and it is commonly overpressured.

70

71 **2. MATERIAL AND METHODS / EXPERIMENTAL DETAILS / METHODOLOGY** 72 **(ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)**

73

74 Heat is a form of energy which flows from a hot region to a cold region. The physical
75 property which determine the direction of heat flow is temperature and the rate at which heat
76 is transported through a solid material is a function of temperature gradient [9, 10, 11,12].
77 The higher the temperature gradient, the faster the heat flow. Heat flow through sedimentary
78 basins mainly by conduction following the heat flow equation:

$$Q = -KdT/dz \quad (1)$$

Where

K = thermal conductivity of the material

Q = heat flow

dT = change in temperature

dz = change in depth

The negative sign is as a result of heat flow from high to low temperatures. The thermal conductivity is the assumed mean of heat conductivity for all the components in the body. Considering a one-dimensional sedimentary column with no erosion or deposition and a constant heat flow from the earth's interior, the column may eventually reached a steady state of thermal equilibrium in which the temperature at any point is steady. At the thermal equilibrium state, the temperature-depth profile is known as geotherm [13, 14, 2]. The temperature at the steady state can be obtained by integrating equation 1, to obtained

$$T(z) = T_o + Q_o Z / K \quad (2)$$

Where

T(z) = Temperature at depth z

T_o = Surface temperature

Q_o = surface heat flow

The total heat flow in the sediment is due to radioactive heat production in the sediment and heat flow from the interior of the earth. The steady state temperature equation in the sedimentary column when heat is produced in the column by radioactive elements is given as

$$\frac{\partial^2 T}{\partial z^2} = A / K \quad (3)$$

Where

A = Heat production in the sediment (mWm⁻³),

K = Thermal conductivity (Wm⁻¹ °C)

T = Temperature (°C)

Z = depth (m)

Equation 3 is a second order differential equation and it can be solved to obtain the temperature by integrating the equation twice. The solution of the equation require two boundary conditions. One of the boundary condition is a constant temperature or heat flow at the surface and the other one is the temperature or heat flow at the base of the sediment column. Integrating equation 3, we obtain

$$Q = \partial T / (\partial z) = AZ/K + C1 \quad (4)$$

In order to obtain the equation for T, the following two boundary conditions were applied;

Temperature T = 27 °C at z = 0

And

Surface heat flow $Q = -k \partial T / \partial z = -Q_0$ at z = 0.

The surface temperature in the study area is 27°C [15]. The surface heat flow $Q = -Q_0$ is negative because heat flows upwards out of the subsurface, which is in the negative z direction. Applying the second boundary condition to equation 4, then

$$C1 = Q_0/k \quad (5)$$

Substituting equation 5 into equation 4, we obtain

$$Q = \partial T / (\partial z) = -Az/k + Q_0/k \quad (6)$$

Integrating equation 6, we obtain

$$T = -Az^2/2k + Q_0z/k + c2 \quad (7)$$

Applying the first boundary condition to equation 7, then

$$C2 = 27 \quad (8)$$

Therefore, putting equation 8 into 7, then

$$T = -Az^2/2k + Q_0z/k + 27 \quad (9)$$

In this work, the geotherm of the study area will be computed based on surface internal observations. The observations are surface heat flow, heat production in the sediment and thickness of the sediment. Equation 9 was used for estimating the vertical variation of subsurface temperature distribution in the studied region. The model assumed that the studied area is made up of one layer (one-layer model). The computed geotherm was compared with bottom hole temperatures from three wells in the Awa oil Field.

3. RESULTS AND DISCUSSION

Many researchers have computed the geothermal gradient and heat flow of the Niger Delta [10, 11]. The average surface heat flow and temperature are 50 Wm⁻² and 27°C respectively. The average radiogenic heat production is about 2.0 μWm⁻³ [16]. These values were used in equation 9 to estimate the temperature distribution in the study area. The result

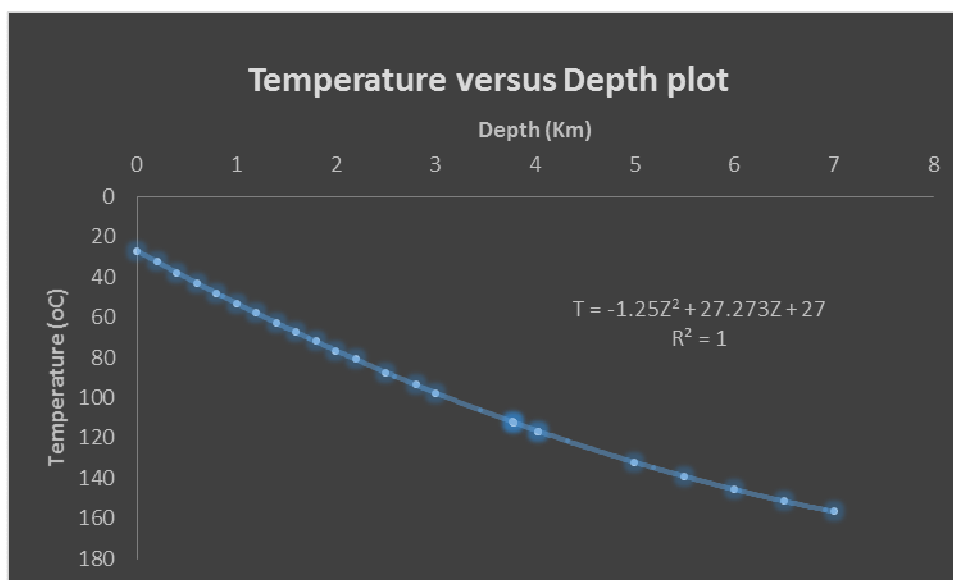


Fig.2a: Subsurface Temperature distribution

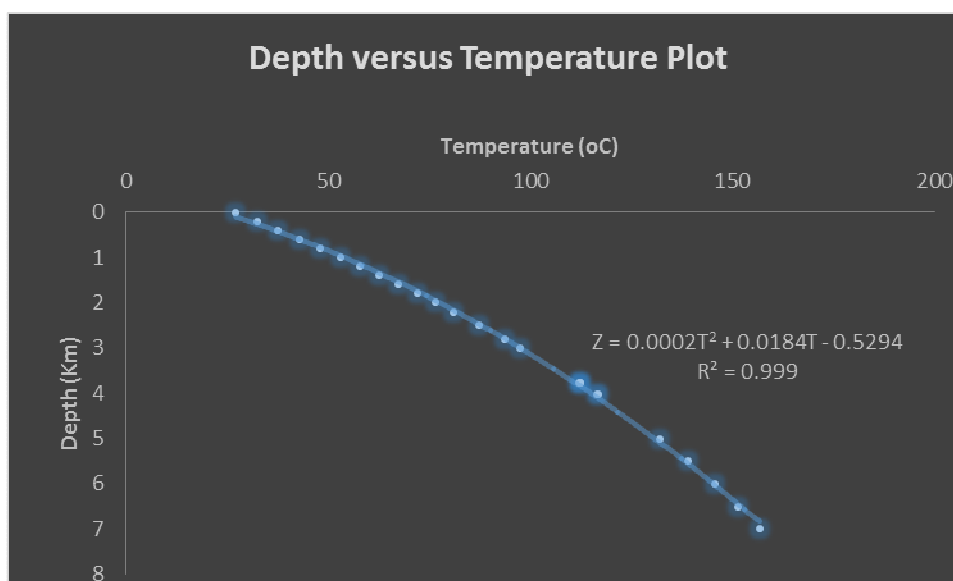


Fig.2b: Subsurface Temperature distribution

Figure 2a is a plot of model temperature versus depth. A polynomial trend with regression coefficient of one (1) was fitted to the curve. The high value of R2 is an indication that the polynomial equation can be used to determine temperature at any given depth (especially for depth less than 7Km) with confident. The geotherm (Fig. 2b) shows a gradual increase in temperature with depth. Although at greater depths (above 7Km), there is some challenges

154 in the confidence in the equation because of the polynomial nature of the solution. The depth
 155 interval (0-7Km) within which there is confidence in the model falls between the Benin and
 156 Agbada Formations in the Niger Delta. The total thick of the two formations is approximately
 157 6-7Km.

158 In order to test the accuracy of the model, the computed geotherm was compared with
 159 bottom hole temperatures obtained at different depths in three wells in the Awa oil field
 160 (Table 1). The measured bottom hole temperature and their corresponding depth for the
 161 three wells are shown in columns 3 and 2 respectively. The computed temperature at the
 162 various depths using the analytical model (equation 9) is given in column 4. Column 5 of the
 163 table is the difference between the measured and computed temperatures. The difference is
 164 within tolerance level because it ranges between -2.9 and 6.0.

165 Table 1: Measured and Computed Bottom Hole Temperature for Three Wells

166	well	Depth (Km)	Bottom Hole		
167			Temp oC	Computed Temp	Difference (Bot Temp-Comp.Temp)
168	Well1	3.218	98.89	101.8192	-2.92923
169		3.21716	98.89	101.8031	-2.91308
170		3.21564	98.89	101.7738	-2.88385
171		3.80634	117.22	112.699	4.521008
172		3.80665	117.22	112.7045	4.515503
173		3.80695	116.67	112.7098	3.960176
174		3.80875	117.22	112.7418	4.478221
175	well2				
176		3.039	97.78	98.33742	-0.55742
177		3.051	97.78	98.57334	-0.79334
178		3.206	107.22	101.5883	5.631681
179		3.330	107.22	103.9571	3.262943
180		3.3395	107.22	104.1369	3.083053
181		3.205	107.22	101.5691	5.65094
182		3.380	111.11	104.9013	6.208682
183		3.394	111.11	105.1646	5.945409
184		3.390	111.11	105.0894	6.02058

185

186	well3	2985.2	92.78	97.27527	-4.49527
187		2.981	92.78	97.19205	-4.41205
188		2.985	92.78	97.27131	-4.49131
189		2.980	92.78	97.17223	-4.39223
190		3.041	101.67	98.37676	3.293238
191		3.044.2	101.67	98.43969	3.230306
192		3.176	101.67	101.0095	0.660538
193		3.1766	101.67	101.0211	0.648939

194

195 Most oil wells drilled in the Niger Delta are within the Benin and Agbada Formations. The
 196 maximum depth drilled so far is approximately 4 Km. Therefore the Temperature of the basin
 197 for depths more than 4km can only be obtained by extrapolating the temperature into the
 198 subsurface. The result of the difference between the computed temperature and the
 199 measured temperature shows that the values are very similar and the model can be trusted
 200 and applied in the upper region of the basin especially the Benin and Agbada Formations.
 201 The major limitation of the model is its polynomial nature which is responsible for the
 202 reversal of the temperature at greater depth.

203

204 **4. CONCLUSION**

205 In this paper, the 1-D steady-state heat conduction equation for one layer model has been
 206 solved and applied to part of the Niger Delta sedimentary basin. . The techniques presented
 207 has helped in obtaining exact analytical solutions for the Fourier one dimensional heat flow.
 208 Comparing the temperature generated with the solution to the temperature obtained from
 209 bottom hole temperature of three wells shows that the solution give a good match. The
 210 computed temperature structure provides useful information on the thermal state of a
 211 sedimentary basin.

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