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Impact of Soil Ambient Temperature on the Accuracy of Measured Thermal Resistivity

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***Abstract**:*

Comprehensive knowledge of soil thermal resistivity is important for the design and installation of buried pipeline and cables, as build up of heat within the vicinity of the buried pipeline could cause it to crack and rust, or the cable becomes overheated and melts. Hence, the aim of this research work is to examine the effect of soil ambient temperature on the measured thermal resistivity values. To achieve this, six thermal resistivity measurements were carried out at the same point, at a depth of 0.5 m, within the space of 3 hours intervals between each measurement, for 15 hours. The ambient soil temperature was noted each time the thermal resistivity of the soil was determined by making use of heating element and a digital thermometer as the probe to monitor temperature increase with time. The range of the determined thermal resistivity is between 0.200030345 oCm/W to 0.404745201 oCm/W, with a significant difference of 0.204714856 oCm/W, that is comparable to the difference between thermal resistivity of sand and water. The results from the plotted graph of temperature against thermal resistivity with positive slope, gave a good indication that the thermal resistivity of the soil increase with increase in ambient soil temperature. The implications of this research work therefore is that the thermal resistivity values measured in the early hours, will be different from thermal resistivity values measured at noon, equally different from thermal resistivity value measured after sunset. Therefore the need for standardization becomes very paramount among the international scientific community for the purpose of harmonization. The notable difference between thermal resistivity measured in situ and thermal resistivity measured in the laboratory could be attributed to soil ambient temperature difference.

Keywords

Ambient Soil Temperature, Thermal Resistivity, Heat input. Pipeline, Cable

1. Introduction

Adequate and precise knowledge of the thermal property of soil is important for the design and installation of underground pipelines and transmission cables. A build up of heat around buried pipeline or transmission cable could cause the pipeline to crack and rust, or cause the cable to become overheated and melt. Soil thermal resistivity measures the ability of the soil to resist or dissipate heat. It is express mathematically as;

$$\sigma = \frac{4\pi}{Q}\left[\frac{T_2 - T_1}{ln\left(\frac{t_2}{t_1}\right)}\right]$$

Where
$\sigma = Soil\ Thermal\ Resistivity\ ℃\ m/W$
$Q = Heat\ Input\ in\ W/m$
$T_1 = Temperature\ at\ time\ t_1$
$T_2 = Temperature\ at\ time\ t_2$

The aim of this research work therefore is to investigate the influence of soil ambient temperature on the result obtained from thermal resistivity measurement. The soil ambient temperature refers to the surrounding or background temperature of the soil at a given time. The soil ambient temperature is dynamic, meaning it can change with change in environmental temperature. To achieve a very precise and high fidelity result in thermal resistivity survey the effect of the ambient temperature on the thermal resistivity result has to be investigated and subsequently be put into consideration when carrying out a thermal resistivity test. Considering the previous work done by other researchers, Gaylon and Keith, 2014, has earlier Stated that “Soil and backfill thermal properties must be known for a safe and successful underground power cable installation”. Soil thermal resistivity is one of the most important values that an engineer must know to calculate the amount of current any particular cable can be allowed to carry (Keith, 2014 et al). Accurate modelling of heat transfer from a pipeline to the ambient will impact all aspects of pipeline simulation; from capacity estimation and inventory to modelled outlet temperatures. Accurate simulations rely on accurate measurements of fluid properties and on the pipeline flow model. (Filip et al, 2015).

The instruments used for this survey include high precision Digital thermometer with probe, 0.08 m heating element probe, 12 volts battery, multichannel Multimeter, digital stopwatch timer and a small drilling tool.

2. Location of the Study Area

The study area is located at Yenagoa Bayelsa State Nigeria, with latitude 4°55'31.00"N and longitude 6°17'56.00"E, with an average elevation of 15 m, above sea level, after Collins 2014. The imagery map indicating the sampled point is shown in figure 1.

Figure 1: Imagery map indicating the sampled point, where the six reading were obtained

3. Geology of the area

The Formation of the present Niger Delta started during Early Paleocene as a result of the built up of fine grained sediments eroded and transported to the area by the River Niger and its tributaries. The regional geology of the Niger Delta consists of three lithostratigraphic units; Akata, Agbada and Benin Formations, overlain by various types of Quaternary Deposits (Short and Stauble, 1967), (Wright et al 1985), (Kogbe, 1989). These Quaternary Sediments, according to Osakuni, and Abam (2004) are largely alluvial and hydromorphic soils and lacustrine sediments of Pleistocene age.

4. Data Acquisition

Data acquisition started with location of appropriate point for the survey made up of undisturbed soil. The top soil majorly composed of humus organic material was removed by excavation. The soil was dug up to a depth of 0.5 m with a shovel, followed by drilling of a hole of about 0.10 m deep. The probe made up of the thermocouple digital thermometer and heating element was inserted into the hole, and good contact between the hole and the probe was ensured. The current flowing in the circuit and voltage of the battery was measured and recorded with the help of the Multimeter. The ambient temperature of the soil was recorded when the reading on the digital thermometer was steady. The circuit was completed by connecting the terminals of the heating element to the battery, at the same time the stop watch was started simultaneously. The readings on the digital thermometer after 0, 5, 10, 15, 30, 45 and 60 s were noted and recorded; subsequently readings were taken every 30 s up to 30 minutes. The readings were carried out for T1, T2, T3, T4, T5 and T6, at 3 hours interval and different ambient temperatures. The same hole was used to acquire the six different readings without removing the probe at any time or alteration of its position and depth. The recorded values were taken to the laboratory for processing.

5. Data Processing

The recorded temperature increase with time were entered in a spreadsheet and used to plot a graph of temperature increase versus time for the six different readings shown in figure 2-7. The measured resistance and current flowing in the circuit were used to calculate the heat input. The heat input was used to calculate the thermal resistivity of the earth by determining the slope of temperature versus the natural log of time graph, that falls within the steady state portion of the graph. The various thermal resistivity values determined at different ambient temperature were plotted against the various ambient temperatures, figure 8, to ascertain their relationship.

6. Results

Tables containing the heat input and recording parameters, in addition to tables of recorded temperature with time at various points T1, T2, T3, T4, T5 and T6 are shown from table 1 to 11. The corresponding graphs of temperature versus time are shown in figure 2 to figure 7. Each graph started with a very steep slope which represent the period the probe was heating up, and later attain the steady state that tapered out at a later time and high temperature. The data were recorded at time range of 0 to 1800 s. The ambient temperature range of 27.1 ºC to 29.2 ºC recorded within an interval of 3 hours for 15 hours, along with the thermal resistivity values measured at the six points are shown in table 12. The range of measured Thermal Resistivity is between 0.200030345ºCm/W to 0.404745201 ºCm/W, with a difference of 0.204714856 ºCm/W between these extreme values, which is a quite significant value comparable to the thermal resistivity difference between sand and water, (Gaylon and Keith, 2014). A close examination of figure 8 which is a graph of Thermal Resistivity versus Ambient Temperature showed that thermal resistivity increases with increase in the same soil ambient temperature. Base on the plotted graph the expression relating thermal resistivity to ambient temperature was determined to be; T=0.095A-2.367, where T stand for thermal resistivity and A stand for ambient soil temperature. From the expression the slope of the graph which indicated the rate at which thermal resistivity increases with temperature was determined to be 0.095. Being a positive slope, it gave a clear confirmation that measured thermal resistivity of a given soil increases with increase in soil ambient temperature.

Table 1. Data Acquisition Parameters for T1

Heat Input Parameters	Heat Input Parameters Values
Current (A)	0.1723
Resistance (Ohms)	73.3
Voltage (V)	12.83
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calculated using Current and Resistance	27.20097946
Date	10/04/2019
Ambient Soil Temperature	27.1 °C
Time of Recording	6am

Table 2. Measured temperature increase with time for T1

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	27.1	23	540	29.8	45	1200	30.3
2	5	27.1	24	570	29.8	46	1230	30.3
3	10	27.2	25	600	29.9	47	1260	30.3
4	15	27.4	26	630	29.9	48	1290	30.3
5	30	27.8	27	660	30	49	1320	30.3
6	45	27.9	28	690	30	50	1350	30.3
7	60	28.2	29	720	30	51	1380	30.3
8	90	28.5	30	750	30.1	52	1410	30.3
9	120	28.8	31	780	30.1	53	1440	30.3
10	150	28.9	32	810	30.1	54	1470	30.3
11	180	29.1	33	840	30.2	55	1500	30.5
12	210	29.2	34	870	30.2	56	1530	30.5
13	240	29.3	35	900	30.2	57	1560	30.5
14	270	29.3	36	930	30.1	58	1590	30.5
15	300	29.4	37	960	30.2	59	1620	30.5
16	330	29.5	38	990	30.2	60	1650	30.5
17	360	29.5	39	1020	30.2	61	1680	30.5
18	390	29.6	40	1050	30.2	62	1710	30.5
19	420	29.6	41	1080	30.2	63	1740	30.5
20	450	29.8	42	1110	30.3	64	1770	30.5
21	480	29.8	43	1140	30.3	65	1800	30.5
22	510	29.8	44	1170	30.3	Thermal Resistivity 0.200030345 °Cm/W		

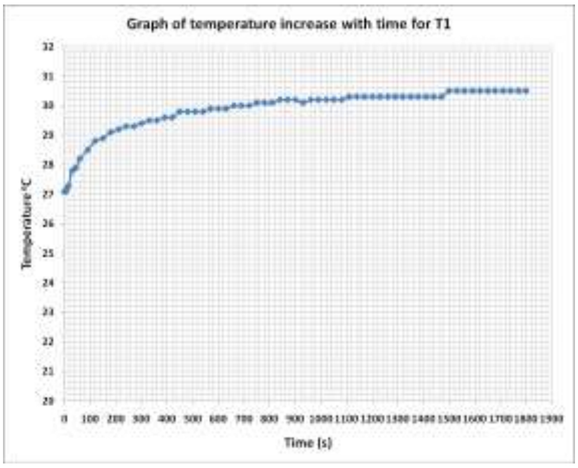

Figure 2. Graph of Temperature oC versus Time (s) for T1. Calculated Thermal Resistivity value of 0.200030345 ºCm/W.

Table 3: Data Acquisition Parameters for T2

Heat Input Parameters	Heat Input Parameters Values
Current (A)	0.1716
Resistance (Ohms)	73.3
Voltage (V)	12.91
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	26.9804106
Date	10/04/2019
Ambient Soil Temperature	28.1 °C
Time of Recording	9am

Table 4: Measured temperature increase with time for T2

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	28.1	23	540	31.3	45	1200	32
2	5	28.1	24	570	31.3	46	1230	32
3	10	28.2	25	600	31.4	47	1260	32
4	15	28.4	26	630	31.4	48	1290	32.1
5	30	28.8	27	660	31.5	49	1320	32.1
6	45	29.2	28	690	31.5	50	1350	32.1
7	60	29.3	29	720	31.6	51	1380	32.1
8	90	29.8	30	750	31.6	52	1410	32.1
9	120	29.9	31	780	31.6	53	1440	32.1
10	150	30.1	32	810	31.7	54	1470	32.1
11	180	30.3	33	840	31.7	55	1500	32.1
12	210	30.5	34	870	31.8	56	1530	32.1
13	240	30.5	35	900	31.8	57	1560	32.2
14	270	30.7	36	930	31.8	58	1590	32.2
15	300	30.8	37	960	31.9	59	1620	32.2
16	330	30.8	38	990	31.9	60	1650	32.2
17	360	30.9	39	1020	31.9	61	1680	32.2
18	390	31.1	40	1050	31.9	62	1710	32.3
19	420	31.1	41	1080	31.9	63	1740	32.3
20	450	31.2	42	1110	31.9	64	1770	32.3
21	480	31.2	43	1140	32	65	1800	32.3
22	510	31.2	44	1170	32	Thermal Resistivity 0.336109371 °Cm/W		

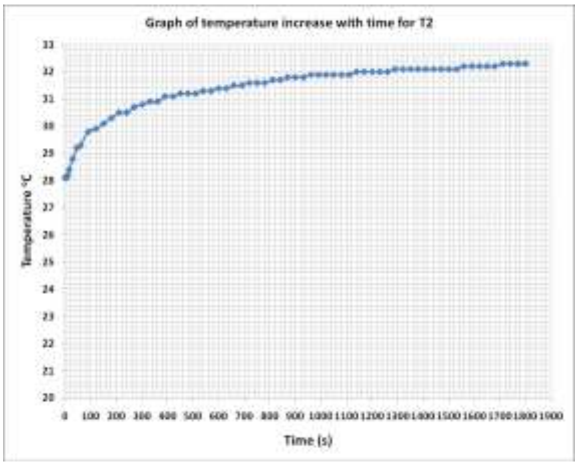

Figure 3: Graph of Temperature oC versus Time (s) for T2. Calculated Thermal Resistivity value of 0.336109371 ºCm/W.

Table 4: Data Acquisition Parameters for T3

Heat Input Parameters	Heat Input Parameters Values
Current (A)	0.1715
Resistance (Ohms)	73.3
Voltage (V)	12.89
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	26.94897406
Date	10/04/2019
Ambient Soil Temperature	28.2 °C
Time of Recording	12noon

Table 5: Measured temperature increase with time for T3

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	28.2	23	540	31.2	45	1200	31.8
2	5	28.2	24	570	31.2	46	1230	31.8
3	10	28.4	25	600	31.3	47	1260	31.8
4	15	28.5	26	630	31.3	48	1290	31.8
5	30	28.9	27	660	31.3	49	1320	31.9
6	45	29.2	28	690	31.4	50	1350	31.9
7	60	29.3	29	720	31.4	51	1380	31.9
8	90	29.8	30	750	31.5	52	1410	31.9
9	120	30	31	780	31.5	53	1440	31.9
10	150	30.2	32	810	31.5	54	1470	31.9
11	180	30.3	33	840	31.5	55	1500	31.9
12	210	30.4	34	870	31.5	56	1530	31.9
13	240	30.5	35	900	31.5	57	1560	32.1
14	270	30.6	36	930	31.6	58	1590	32.1
15	300	30.8	37	960	31.7	59	1620	32.1
16	330	30.8	38	990	31.7	60	1650	32.1
17	360	30.8	39	1020	31.8	61	1680	32.1
18	390	30.9	40	1050	31.8	62	1710	32.1
19	420	31	41	1080	31.8	63	1740	32.1
20	450	31	42	1110	31.8	64	1770	32.1
21	480	31.1	43	1140	31.8	65	1800	32.1
22	510	31.2	44	1170	31.8	Thermal Resistivity	0.336501449 °Cm/W	

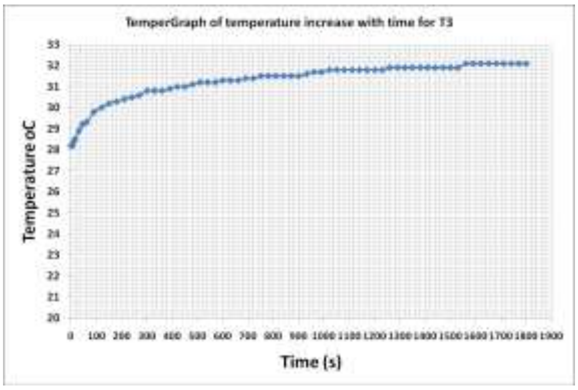

Figure 4: Graph of Temperature oC versus Time (s) for T3. Calculated Thermal Resistivity value of 0.336501449 ºCm/W.

Table 6: Data Acquisition Parameters for T4

Heat Input Parameters	Heat Input Parameters Values
Current (A)	0.1714
Resistance (Ohms)	73.3
Voltage (V)	12.9
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calculation using Current and Resistance	26.91755585
Date	10/04/2019
Ambient Soil Temperature	28.6 °C
Time of Recording	3pm

Table 7: Measured temperature increase with time for T4

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	28.6	23	540	31.8	45	1200	32.3
2	5	28.7	24	570	31.8	46	1230	32.3
3	10	28.8	25	600	31.8	47	1260	32.3
4	15	28.9	26	630	31.8	48	1290	32.3
5	30	29.2	27	660	31.9	49	1320	32.3
6	45	29.6	28	690	31.9	50	1350	32.4
7	60	29.8	29	720	31.9	51	1380	32.4
8	90	30.2	30	750	31.9	52	1410	32.4
9	120	30.4	31	780	32	53	1440	32.4
10	150	30.6	32	810	32	54	1470	32.4
11	180	30.8	33	840	32.1	55	1500	32.4
12	210	30.9	34	870	32.1	56	1530	32.4
13	240	30.9	35	900	32.1	57	1560	32.4
14	270	31.1	36	930	32.2	58	1590	32.5
15	300	31.2	37	960	32.2	59	1620	32.5
16	330	31.3	38	990	32.2	60	1650	32.5
17	360	31.3	39	1020	32.2	61	1680	32.5
18	390	31.3	40	1050	32.2	62	1710	32.5
19	420	31.5	41	1080	32.3	63	1740	32.5
20	450	31.5	42	1110	32.3	64	1770	32.5
21	480	31.5	43	1140	32.3	65	1800	32.5
22	510	31.8	44	1170	32.3	Thermal Resistivity	0.336894214 °Cm/W	

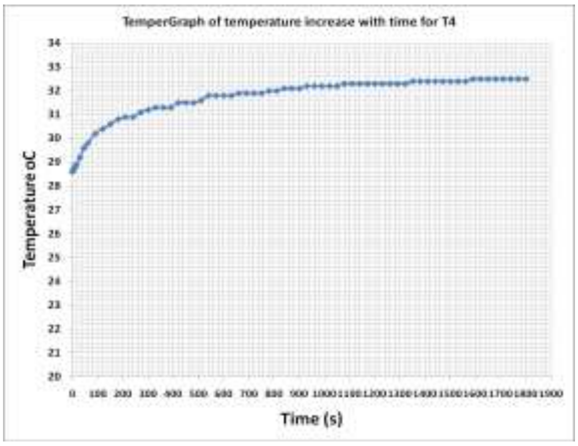

Figure 5: Graph of Temperature oC versus Time (s) for T4. Calculated Thermal Resistivity value of 0.336894214 ºCm/W

Table 8: Data Acquisition Parameters for T5

Heat Input Parameters	Heat Input Parameters Values
Current (A)	0.1713
Resistance (Ohms)	73.3
Voltage (V)	12.89
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calculation using Current and Resistance	26.88615596
Date	10/04/2019
Ambient Soil Temperature	29.1 °C
Time of Recording	6pm

Table 9: Measured temperature increase with time for T5

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	29.1	23	540	32.1	45	1200	32.8
2	5	29.1	24	570	32.2	46	1230	32.8
3	10	29.5	25	600	32.2	47	1260	32.8
4	15	29.3	26	630	32.2	48	1290	32.8
5	30	29.8	27	660	32.2	49	1320	32.9
6	45	30.1	28	690	32.3	50	1350	32.9
7	60	30.3	29	720	32.3	51	1380	32.9
8	90	30.6	30	750	32.4	52	1410	32.9
9	120	30.8	31	780	32.4	53	1440	32.9
10	150	31.0	32	810	32.4	54	1470	32.9
11	180	31.2	33	840	32.5	55	1500	32.9
12	210	31.3	34	870	32.5	56	1530	32.9
13	240	31.4	35	900	32.5	57	1560	32.9
14	270	31.5	36	930	32.6	58	1590	32.9
15	300	31.7	37	960	32.5	59	1620	32.9
16	330	31.8	38	990	32.5	60	1650	32.9
17	360	31.8	39	1020	32.7	61	1680	32.9
18	390	31.9	40	1050	32.7	62	1710	32.9
19	420	31.9	41	1080	32.7	63	1740	33.1
20	450	32.0	42	1110	32.7	64	1770	33.1
21	480	32.0	43	1140	32.7	65	1800	33.1
22	510	32.1	44	1170	32.8	Thermal Resistivity	0.404745201 °Cm/W	

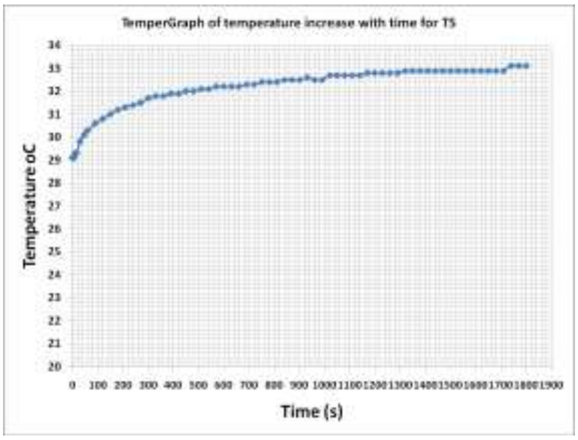

Figure 6: Graph of Temperature oC versus Time (s) for T5. Calculated Thermal Resistivity value of 0.404745201 ºCm/W

Table 10: Data Acquisition Parameters for T6

Heat Input Parameters	Heat Input Parameters Values
Current (A)	0.1709
Resistance (Ohms)	73.3
Voltage (V)	12.89
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calculation using Current and Resistance	26.76073966
Date	10/04/2019
Ambient Soil Temperature	29.2℃
Time of Recording	9 pm

Table 11: Measured temperature increase with time for T6

S/N	Time (s)	Temperature ℃	S/N	Time (s)	Temperature ℃	S/N	Time (s)	Temperature ℃
1	0	29.2	23	540	32.1	45	1200	32.7
2	5	29.2	24	570	32.2	46	1230	32.7
3	10	29.3	25	600	32.2	47	1260	32.8
4	15	29.5	26	630	32.2	48	1290	32.8
5	30	29.9	27	660	32.3	49	1320	32.8
6	45	30.1	28	690	32.3	50	1350	32.8
7	60	30.3	29	720	32.3	51	1380	32.8
8	90	30.7	30	750	32.3	52	1410	32.8
9	120	30.9	31	780	32.3	53	1440	32.9
10	150	31.1	32	810	32.4	54	1470	32.9
11	180	31.2	33	840	32.4	55	1500	32.9
12	210	31.3	34	870	32.4	56	1530	32.9
13	240	31.4	35	900	32.5	57	1560	32.9
14	270	31.5	36	930	32.5	58	1590	32.9
15	300	31.7	37	960	32.5	59	1620	32.9
16	330	31.7	38	990	32.5	60	1650	32.9
17	360	31.8	39	1020	32.6	61	1680	32.9
18	390	31.9	40	1050	32.6	62	1710	32.9
19	420	31.9	41	1080	32.6	63	1740	32.9
20	450	31.9	42	1110	32.6	64	1770	32.9
21	480	32.1	43	1140	32.6	65	1800	32.9
22	510	32.1	44	1170	32.7	Thermal Resistivity 0.406642071 °Cm/W		

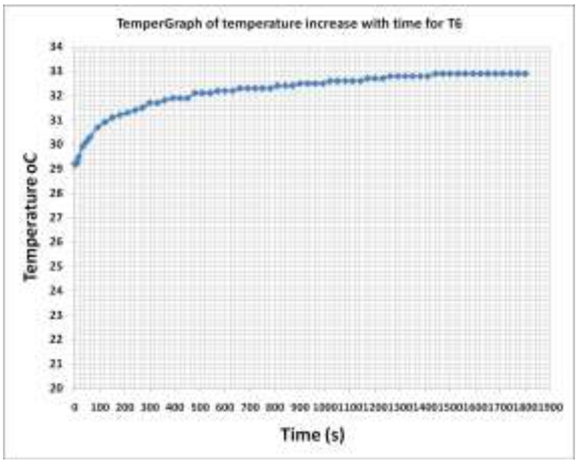

Figure 7: Graph of Temperature oC versus Time (s) for T6. Calculated Thermal Resistivity value of 0.406642071 ºCm/W

Table 12: Ambient temperature and corresponding Thermal Resistivity values

Points	Time of measurement	Ambient Temperature ℃	Thermal Resistivity values ℃m/W
T1	6am	27.1	0.200030345
T2	9am	28.1	0.336109371
T3	12noon	28.2	0.336501449
T4	3pm	28.5	0.336894214
T5	6pm	29.1	0.404745201
T6	9pm	29.2	0.406642071

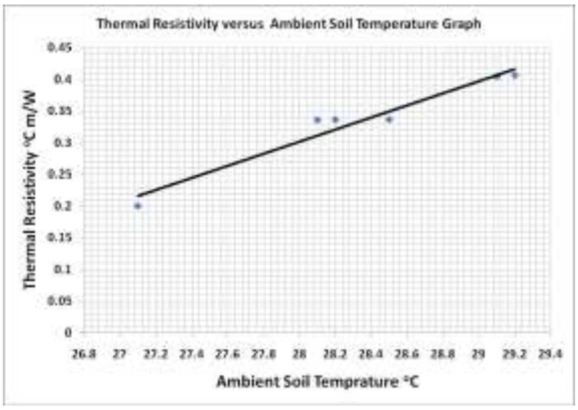

Figure 8: Graph of Thermal Resistivity oCm/W versus Ambient Soil Temperature ºC

7. Conclusion

The experimental result has indicated that soil thermal resistivity increases with Soil ambient temperature. This was confirmed by the positive slope of graph of thermal resistivity versus soil ambient temperature. It was evident that the difference between the two extreme thermal resistivity values which is 0.204714856 oCm/W, is more than the difference between that of sand and water. The optimum safe standard value accepted for buried pipeline and cables is 0.900000000 oC m/W. Therefore a difference in thermal resistivity value of 0.204714856 oCm/W could either mean that the surrounding soil is outside the safety limit with the value of (0.900000000 oC m/W + 0.204714856 oCm/W) 1.104714856 oCm/W, or very safe with a value of (0.900000000 oC m/W- 0.204714856 oCm/W) 0.695285144 oC m/W.

The implication of this research work is that the thermal resistivity value measured in the early morning will be different from the thermal resistivity measured at noon or in the late evening on the same soil, without moving the probe. Standardization is therefore necessary with further research to know what to add or subtract depending on which time the test was conducted. The notable difference between thermal resistivity measured in situ and thermal resistivity measured in the laboratory could be attributed to soil ambient temperature difference.

8. References

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