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Effect of Heat From Buried Metallic Object On Different Soil Textures

***V.C. Ozebo, J.A. Olowofela, R. Bello and A.O. Amure**
Department of Physics,
University of Agriculture, Abeokuta Nigeria.

Abstract

We investigated the effect of heat from buried steel, on clay, loamy and sandy soil using thermography technique. The experiment was performed in a laboratory at Abeokuta, South Western Nigeria, with the objects buried at a depth of 2cm and heated to a temperature of 40^0C . A plot of the variation of the temperature (as the heated object and soil samples cool) with time was done and the thermal signatures recorded. The data from the experiment was used, with the aid of the least square approximation method, to develop a predictive model for some thermal characteristics of the three soil textures. The result also revealed that loamy soil retains the least amount of heat and is therefore recommended as the friendliest for crops and plants.

Keywords: Thermography, Abeokuta, thermal signature, least square approximation, soil texture.

1.0 Introduction

Heat is a universal physical phenomenon, a form of energy which affects both man and his environment. Researchers are continually carrying out studies on its nature and aspects as it relates to various endeavours of human existence. Thermography offers nowadays the possibility of fast imaging of temperature emitted by buried objects [1].

The rate of biological and chemical reaction and hence the rate of crop growth are influenced by the temperature of the soil. The temperature in turn depends directly upon heat capacity of the soil. The amount of temperature change in response to the absorption or release of heat is governed by heat capacity [2], [3], [4].

Crop plants are immobile. They must adapt to prevalent soil and weather conditions. Except for transpiration cooling, plants are unable to adjust their tissue temperatures to any significant extent. On the other hand, plants have evolved several mechanisms that enable them to tolerate higher temperatures. These adaptive thermo-tolerant mechanisms reflect the environment in which a species has evolved and they largely dictate the environment where a crop may be grown [5], [6].

Clearly, many crops in tropical areas are already subjected to heat stress. If temperatures increase further, crop failure in some traditional areas would become more commonplace.

This study is aimed at investigating the effect of heat on soil types by determining:

(i) The level of heat which each identified soil texture could hold at a particular temperature

(ii) The particular soil texture that can easily resist or retain heat for agricultural purposes vis-à-vis crop or plant growth and yield

(iii) A model (predictive equation) governing heat emitted by buried steel objects on soil at a particular temperature with respect to time.

2.0 Materials and Methods

2.0.1 Experimental Procedure

Three identifiable soil types namely, clay, sandy and loamy samples were used in the study, applying thermography technique. This is an established procedure for investigating buried objects for fast imaging of temperature (heat) emitted by such objects [2]. The depth of burial of such objects is 2cm, which is in line with the United Nations standard for landmine detection. Moreover, most agricultural plants /crops are planted at shallow depths.

A temperature sensor was attached to a buried object of dimension, 12cm x 12cm x 0.5cm, to read the heat emitted by the buried object. The heating source was on for a period of few hours sufficient enough for the buried object to absorb significant heat and later switched off to see the cooling pattern of the buried objects. The experiment was carried out in the laboratory in Abeokuta, (latitude 7^o 3´ N and longitude 3^o 3´ E) South-West, Nigeria.

Corresponding authors: V.C. Ozebo, E-mail: chidioz2001@yahoo.com, *Tel.*: +2348066515057.

2.0.2 Empirical Modelling

An empirical model is one which is derived from and based entirely on data. In such a model, relationships between variables are derived by looking at the available data on the variables and selecting a mathematical form which is a compromise between accuracy of fit and simplicity of mathematics. When we have no principles to guild us and no obvious assumptions suggest themselves, we may (with justification) turn to the data to find how some of our variables are related. We thus adopted the idea of least square approximation to fit a polynomial function *P(x)* to a set of data *(x, y)* having a theoretical solution;

$$y = f(x) \tag{2.1}$$

The aim is to minimize the squares of the error. An approximate fit yields a polynomial that passes through the set of points in the best possible manner without being required to pass exactly through any of the points. It must be noted that linear regression is usually unsatisfactory as it is obvious that a line cannot fit all data well especially the data used in this work. Therefore, higher-degree polynomial regression is used in this study.

Consider the nth –degree polynomial:

$$y = a_0 + a_1 x + \cdots + a_n x^n \tag{2.2}$$

Given the N data points (x_i, Y_i), and from equation (2.2), the sum of the squares of the deviations is

$$S(a_0, a_1, \ldots, a_n) = \sum_{i=1}^{N} (e_i)^2 = \sum_{i=1}^{N} (Y_i - a_0 - a_1 x_1 - \cdots . - a_n x_i^n)^2 \tag{2.3}$$

The function $S(a_0, a_1, \ldots, a_n)$ is a minimum when

$$\frac{\partial S}{\partial a_0} = \sum_{i=1}^{N} 2(Y_i - a_0 - a_1 x_1 - \cdots . - a_n x_i^n)(-1) = 0 \tag{2.4a}$$

$$\frac{\partial S}{\partial a_0} = \sum_{i=1}^{N} 2(Y_i - a_0 - a_1 x_1 - \cdots . - a_n x_i^n)(-{x_i}^n) = 0 \tag{2.4b}$$

Dividing equations (2.4a) and (2.4b) by equation (2.2) and re-arranging, yields:

$$a_0 N + a_1 \sum_{i=1}^{N} x_i + \cdots + a_n \sum_{i=1}^{N} x_i^n = \sum_{i=1}^{N} Y_i \tag{2.5a}$$

$$a_0 \sum_{i=1}^{N} x_i^n + a_i \sum_{i=1}^{N} {x_i}^{n+1} + \cdots + a_n \sum_{i=1}^{N} x_i^{2n} = \sum_{i=1}^{N} x_i^n Y_i \tag{2.5b}$$

Equation (2.5) can then be solved for a_0 to a_n by Gauss elimination.

For the purpose of this study, a least square quadratic polynomial approximation in the form of equation (2.6) will be used

$$y = a_0 + a_1 x + a_1 x^2 \tag{2.6}$$

That is, n = 2. Therefore,

$$\begin{aligned} \Sigma y &= n a_0 + a_1 \Sigma x + a_2 \Sigma x^2 \\ \Sigma xy &= a_0 \Sigma x + a_1 \Sigma x^2 + a_2 \Sigma x^3 \\ \Sigma x^2 y &= a_0 \Sigma x^2 + a_1 \Sigma x^3 + a_2 \Sigma x^4 \end{aligned} \tag{2.7}$$

Equation (2.7) can be written in matrix form as

$$\begin{pmatrix} n & \sum x & \sum x^2 \\ \sum x & \sum x^2 & \sum x^3 \\ \sum x^2 & \sum x^3 & \sum x^4 \end{pmatrix}^{-1} \begin{pmatrix} a_o \\ a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} \sum y \\ \sum xy \\ \sum x^2 y \end{pmatrix} \tag{2.8}$$

3.0 Results and Discussion

The temperature of the buried object in each soil texture was read and taken at one hour interval after heating. Table 1 shows the result obtained from the experiment while Figure 1 shows the variation of various soil texture temperatures with time.

It was observed that sandy soil retains the highest heat both at the beginning and at the end of the experiment followed by clay soil while loamy soil retains the lowest amount of heat both at the beginning and the end of the experiment.

Temperature affects the rate of biochemical reaction in crops. It also affects the biological functions of plant including their growth and development. Different crops survive in various temperature ranges.

In the light of the above, knowledge of heat absorption and retention of soil will help in determining the type of soil required for different types of crop.

The modeling was done using data from the experiment. Let time (t) and the temperature (T) for each soil texture, be equal to x and y respectively in equation (2.6). A *3 x 3* matrix was generated using equations (2.7) and (2.8) and solved for a_0, a_1 and a_2, with the aid of Microsoft Student Encarta.

Solving equation (2.8) (i.e. substituting the values of a_0, a_1 and a_2 into equation (2.6) for the three soil samples) give the following model equations:

$$T_{loamy} = 36.3121409090909 - 0.8813314308499t + 0.0294320460242t^2 \tag{3.1}$$

$$T_{Clay} = 36.7877694805195 - 0.8760066188198t + 0.0292440760993t^2 \tag{3.2}$$

$$T_{Sandy} = 38.8986590909091 - 1.1610951355662t + 0.038974752791t^2 \tag{3.3}$$

Table 1: Variation of Temperature of Soil samples with Time

Time (h)	Temperature of Loamy Soil, °C	Temperature of Clay Soil, °C	Temperature of Sandy Soil, °C
0	37.151	37.425	39.743
1	36.715	37.178	39.318
2	34.019	34.704	36.146
3	32.949	33.574	34.704
4	32.484	33.001	33.940
5	32.073	32.562	33.313
6	31.714	32.175	32.820
7	31.382	31.868	32.381
8	31.128	31.612	32.047
9	30.874	31.382	31.740
10	30.697	31.204	31.510
11	30.571	31.052	31.306
12	30.419	30.900	31.103
13	30.268	30.748	30.925
14	30.142	30.621	30.773
15	29.991	30.520	30.621
16	29.865	30.394	30.469
17	29.740	30.293	30.343
18	29.665	30.192	30.243
19	29.640	30.142	30.192

Table 2 shows the data values obtained for loamy soil while Figure 2 was used to compare the experimental with predicted data. In the same vein, tables 3 and 4 show the values for Clay and Sandy soils while Figures 3 and 4 were used to compare the experimental with predicted data.

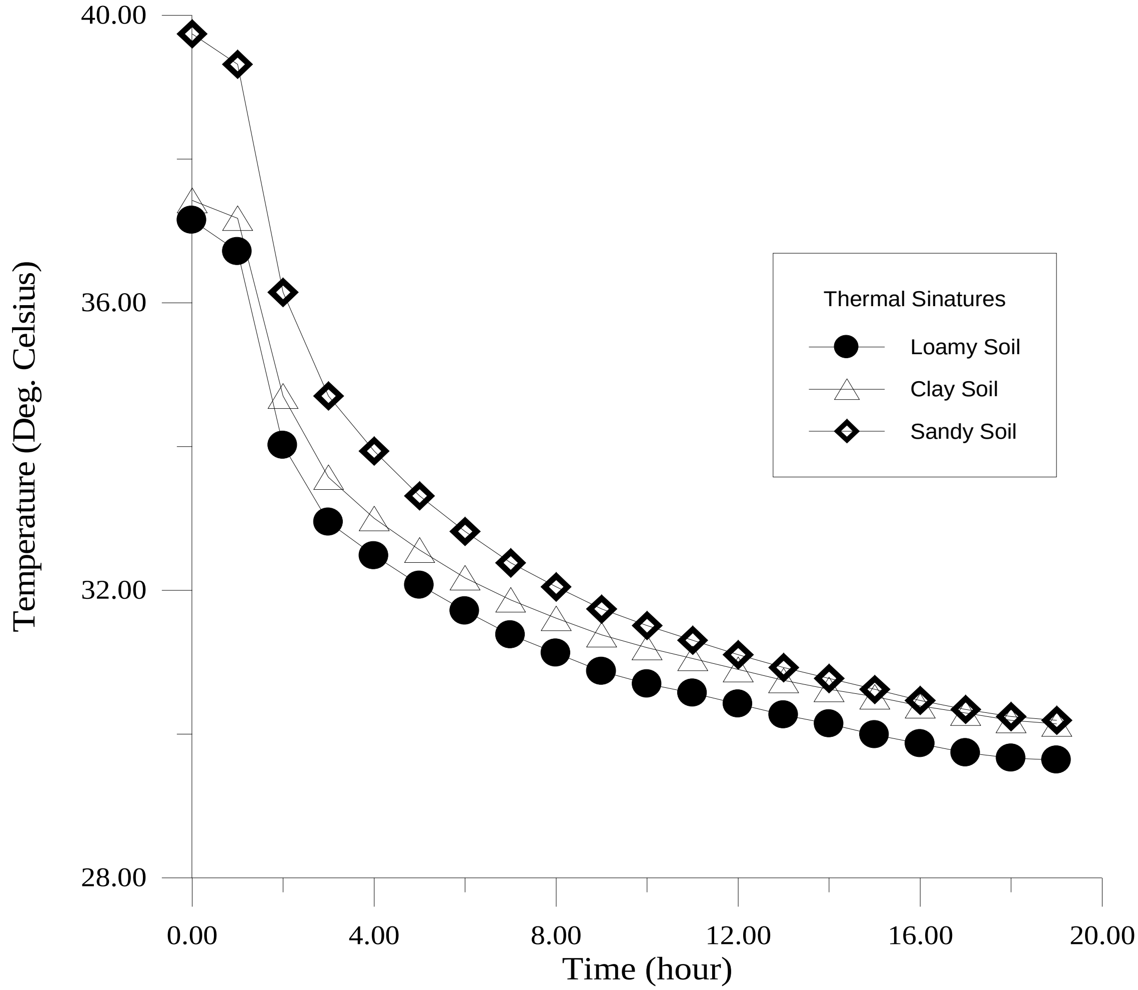

Figure 1. Variation of the three soil texture temperatures with time

It should be noted that substituting the values of t and t^2 from Tables 2, 3 and 4 respectively for the loamy, clay and sandy soil samples, will produce the predicted data for Figures 2, 3 and 4.

Table 2: Data for Modeling Effect of Temperature Emitted by Buried Steel on Loamy soil

	Time,(t) (hour)	Temp.(T) of Loamy Soil, (°C)	t^2	tT	t^3	t^2T	t^4
	0	37.151	0	0	0	0	0
	1	36.715	1	36.715	1	36.715	1
	2	34.019	4	68.038	8	136.076	16
	3	32.949	9	98.847	27	296.541	81
	4	32.484	16	129.936	64	519.744	256
	5	32.073	25	160.365	125	801.825	625
	6	31.714	36	190.284	216	1141.704	1296
	7	31.382	49	219.674	343	1537.718	2401
	8	31.128	64	249.024	512	1992.192	4096
	9	30.874	81	277.866	729	2500.794	6561
	10	30.697	100	306.97	1000	3069.7	10000
	11	30.571	121	336.281	1331	3699.091	14641
	12	30.419	144	365.028	1728	4380.336	20736

	13	30.268	169	393.484	2197	5115.292	28561
	14	30.142	196	421.988	2744	5907.832	38416
	15	29.991	225	449.865	3375	6747.975	50625
	16	29.865	256	477.84	4096	7645.44	65536
	17	29.740	289	505.58	4913	8594.86	83521
	18	29.665	324	533.97	5832	9611.46	104976
	19	29.640	361	563.16	6859	10700.04	130321
Sum	190	631.487	2470.000	5784.915	36100.000	74435.335	562666.000

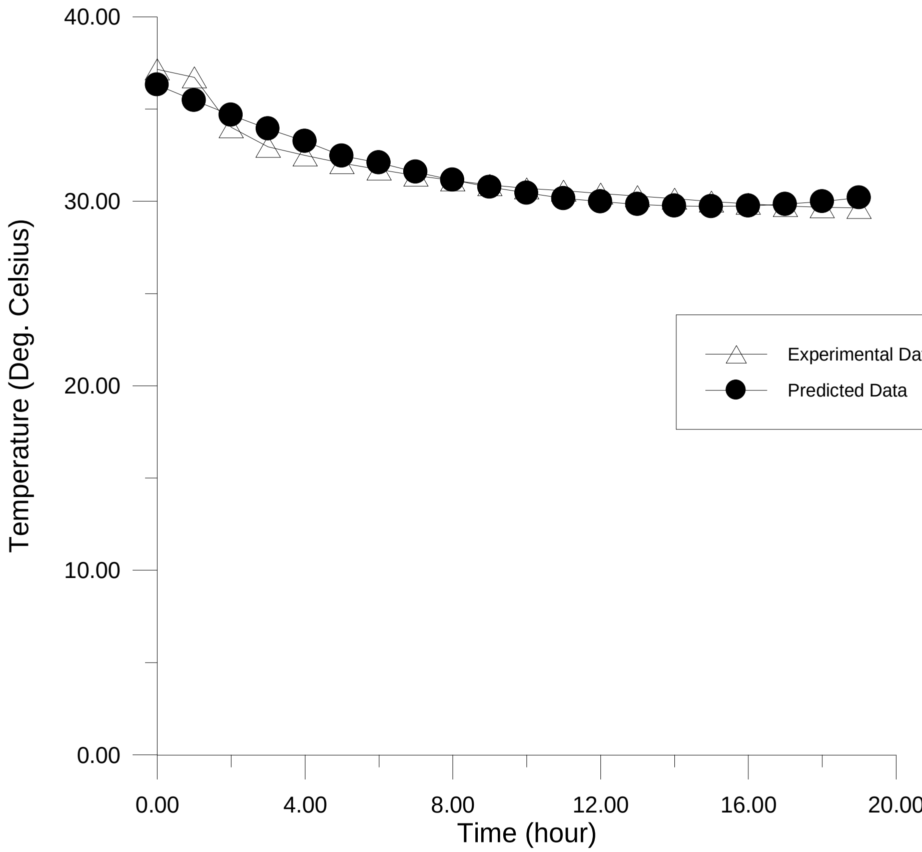

Figure 2. Comparison of Experimental and Predicted Data for loamy soil

Factorizing and generalizing equations (3.1), (3.2) and (3.3), yields:

$$T = 36.3121409090909x - 0.8760066188198yt + 0.0292440760993zt^2 \quad (3.4)$$

Where for loamy, *x = 1*, *y = 1.0060785066*, *z = 1.00642762*

For clay, *x = 1.0130983346*, *y = 1*, *z = 1*

For sandy, *x = 1.0712301208*, *y = 1.3254410533*, *z = 1.3327400961*

The parameters *x*, *y*, and *z* represent the thermometric properties of the soil texture.

Table 3: Data for Modeling Effect of Temperature Emitted by Buried Steel on Clay soil

	Time,(t) (hour)	Temp.(T) of Clay Soil (°C)	t^2	tT	t^3	t^2T	t^4
	0	37.425	0	0	0	0	0
	1	37.178	1	37.178	1	37.178	1
	2	34.704	4	69.408	8	138.816	16
	3	33.574	9	100.722	27	302.166	81
	4	33.001	16	132.004	64	528.016	256
	5	32.562	25	162.81	125	814.05	625
	6	32.175	36	193.05	216	1158.3	1296
	7	31.868	49	223.076	343	1561.532	2401

	8	31.612	64	252.896	512	2023.168	4096
	9	31.382	81	282.438	729	2541.942	6561
	10	31.204	100	312.04	1000	3120.4	10000
	11	31.052	121	341.572	1331	3757.292	14641
	12	30.900	144	370.8	1728	4449.6	20736
	13	30.748	169	399.724	2197	5196.412	28561
	14	30.621	196	428.694	2744	6001.716	38416
	15	30.520	225	457.8	3375	6867	50625
	16	30.394	256	486.304	4096	7780.864	65536
	17	30.293	289	514.981	4913	8754.677	83521
	18	30.192	324	543.456	5832	9782.208	104976
	19	30.142	361	572.698	6859	10881.262	130321
Sum	190	641.547	2470.000	5881.651	36100.000	75696.599	562666.000

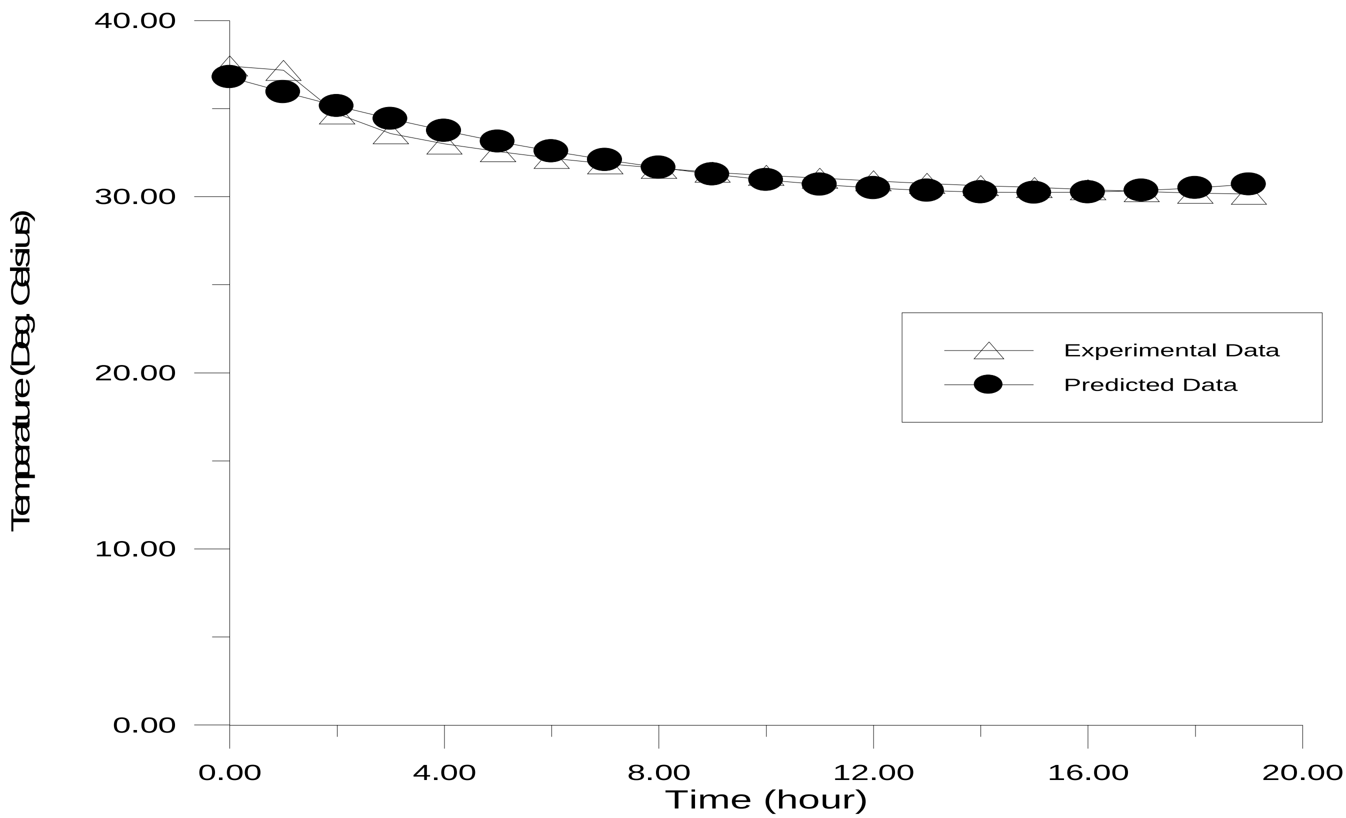

Figure 3. Comparison of Experimental and Predicted Data for Clay soil

Table 4: Data for Modeling Effect of Temperature Emitted by Buried Steel on Sandy soil

	Time,(t) (hour)	Temp. (T) of Sandy Soil (°C)	t^2	tT	t^3	t^2T	t^4
	0	39.743	0	0	0	0	0
	1	39.318	1	39.318	1	39.318	1
	2	36.146	4	72.292	8	144.584	16
	3	34.704	9	104.112	27	312.336	81
	4	33.940	16	135.76	64	543.04	256

	5	33.313	25	166.565	125	832.825	625
	6	32.820	36	196.92	216	1181.52	1296
	7	32.381	49	226.667	343	1586.669	2401
	8	32.047	64	256.376	512	2051.008	4096
	9	31.740	81	285.66	729	2570.94	6561
	10	31.510	100	315.1	1000	3151	10000
	11	31.306	121	344.366	1331	3788.026	14641
	12	31.103	144	373.236	1728	4478.832	20736
	13	30.925	169	402.025	2197	5226.325	28561
	14	30.773	196	430.822	2744	6031.508	38416
	15	30.621	225	459.315	3375	6889.725	50625
	16	30.469	256	487.504	4096	7800.064	65536
	17	30.343	289	515.831	4913	8769.127	83521
	18	30.243	324	544.374	5832	9798.732	104976
	19	30.192	361	573.648	6859	10899.312	130321
Sum	190	653.637	2470.000	5929.891	36100.000	76094.891	562666.000

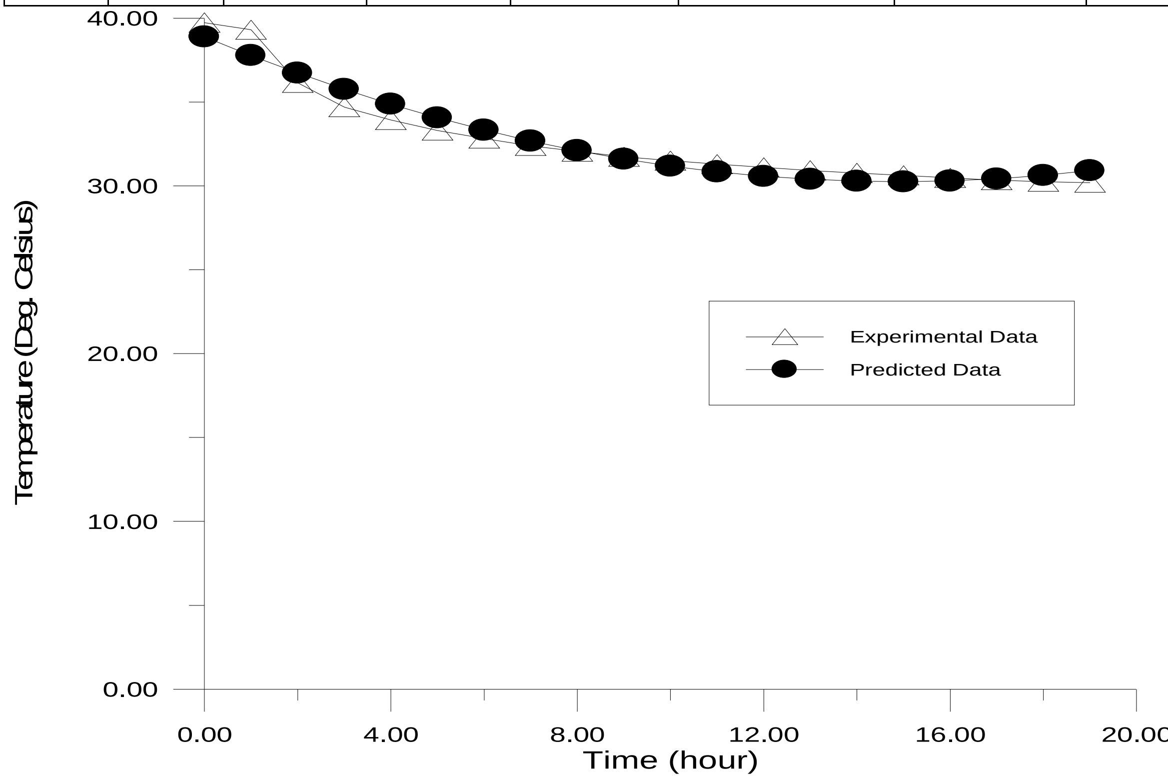

Figure 4. Comparison of Experimental and Predicted Data for Sandy soil

4.0 Conclusion

Investigation on heat emitted by buried steel object as a function of soil types was carried out in this study. Three steel material were buried in three different soil textures namely, clay, loamy and sand under a control temperature of 40^0C. Measurements were taken at one hour intervals. It was observed that sandy soil retains the highest quantity of heat both at the beginning and end of the experiment, followed by clay soil while loamy soil retains the lowest amount of heat during the same period. This may be attributed to the fact that the ability of materials to absorb or give off heat depends on their density. The less dense materials will absorb heat faster, but they will also give it off quickly.

An equation was generated from the data obtained using the least square approximation method. This equation can be used to predict the heat emitted by buried steel objects in clay, loamy and sandy soils using their respective thermometric properties obtained in this study.

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