A Multifunctional Equipment for Early Detection of Leakages from Nuclear Waste Containment Estimating Thermal and Electrical Resistivity, Moisture Content of Soil

A thesis submitted in partial fulfilment of the requirements for the degree of

BACHELOR OF TECHNOLOGY IN CIVIL ENGINEERING

BY

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UNDER THE GUIDANCE OF
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NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

CERTIFICATE

This is to certify that this report entitled, “ ***A Multifunctional Equipment for Early Detection of Leakages from Nuclear Waste Containment Estimating Thermal and Electrical Resistivity, Moisture Content of Soil****” submitted by Siddharth Das (109CE037) in partial fulfilment for the award of Bachelor of Technology Degree in Civil Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision.*

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/institute for the award of any degree or diploma.

DATE:

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ABSTRACT

Nuclear accidents can be due to release of radioactive elements into air, into water body and soil, leakages from outdated reactors, etc. Moisture or humidity detection is the primary leakage detection method, but there may be variation in the moisture content of soil around the nuclear storage tanks due to various other reasons, such as rainfall or change in groundwater table, which gives inconsistent warning. In the present study multifunctional equipment is fabricated that estimates soil thermal resistivity, electrical resistivity and the moisture content in the soil. The thermal probe was calibrated using standard glycerol and the electrical probe was calibrated using sodium chloride and potassium chloride solution. A Laboratory model study was conducted simulating the nuclear leakage using sodium thiosulphate pentahydrate solution. The difference in thermal and electrical resistivity corresponding to moisture leakage and high conductivity fluid solution was identified. The equipment will help us in predicting the soil thermal and electrical properties, which can be used to give timely warning if there is any abnormal release/leakage of nuclear wastes from the storage tanks.

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CHAPTER 1

INTRODUCTION

Nuclear power is the fourth largest source for producing electricity in India after thermal, hydro and renewable sources of electricity. As per 2012 statistics, India has 20 nuclear reactors in operation in six nuclear power plants, generating 4,780 MW and seven other reactors are under construction and are expected to generate an additional 5,300 MW. India expects to have 14,600 MW nuclear capacities on line by 2020. It aims to supply 25% of electricity from nuclear power by 2050. Nuclear power is considered more dependable and better suited to meet rising demands of electricity on large scales, and also helps in achieving our zero greenhouse gas goals other energy sources.

Still, the establishment of nuclear power involves two challenges: 1) safety, 2) economics. It is very difficult to categorize nuclear power as green energy because after the disaster in Fukushima (2011), it has drastically changed the public perception. After the tragedy, more attention is now focused on the safety of outdated design of nuclear reactors as well as safe disposal of nuclear wastes. Some of the nuclear accidents in and outside India are listed in Table 1 and Table 2. Nuclear accidents can be of any type like release of radioactive elements into air, or into water body and soil, failure of any reactor, leakages from outdated reactors, etc. So it is extremely important that nuclear radioactive waste generated by military and civil applications need to be managed in safe, while simultaneously monitoring the leakages from the radioactive waste storage plants.

Some of the methods for detecting the abnormalities due to radioactive leakage in the soil environment includes: 1) detection of anomalous water content of the surrounding soil, 2) radionuclides contained in the leaking water, 3) acoustic leak detection systems, and 4) secondary signals such as temperature, etc. Moisture or humidity detection is the primary leak detection method. So monitoring the moisture content of the soil around the nuclear power plant can be an effective method for determining the leakage but there may be variation in the moisture content of soil around the nuclear storage tanks due to various reasons, such as rainfall or change in groundwater table, giving inconsistent warning. So we have to develop an efficient technology for detecting the leakages from the nuclear storage tanks which should give a confirmative and timely alarm for leakages.

1.1 OBJECTIVE AND SCOPE:

The soil thermal and electrical properties change when there is release of radioactive materials in the soil environment (Shaikh, 2007; Rucker et. al, 2009). So the objective of the study is to identify and monitor a technique for early detection of abnormal radioactive releases to the surrounding underground environment in existing nuclear storage tanks, by simultaneously observing the changes in the soil thermal and electrical properties as well as change in the moisture content. A multifunctional equipment is developed that detects the change in soil thermal resistivity, electrical resistivity and the moisture content in the soil giving timely warning if there is nuclear leakages detected from the nuclear storage tanks.

Table 1. Lists of nuclear accidents in India

DATE	LOCATION	DESCRIPTION
4 May 1987	Kalpakkam, India	Fast Breeder Test Reactor at Kalpakkam refuelling accident that ruptures the reactor core, resulting in a two-year shutdown
10 Sep 1989	Tarapur, Maharashtra, India	Operators at the Tarapur Atomic Power station find that the reactor had been leaking radioactive iodine at more than 700 times normal levels. Repairs to the reactor take more than a year
13 May 1992	Tarapur, Maharashtra, India	A malfunctioning tube causes the Tarapur Atomic Power Station to release 12 curies of radioactivity
31 Mar 1993	Bulandshahr, Uttar Pradesh, India	The Narora Atomic Power Station suffers a fire at two of its steam turbine blades, damaging the heavy water reactor and almost leading to a meltdown
2 Feb 1995	Kota, Rajasthan, India	The Rajasthan Atomic Power Station leaks radioactive helium and heavy water into the Rana Pratap Sagar River, necessitating a two-year shut down for repairs
22 Oct 2002	Kalpakkam, India	Almost 100 kg radioactive sodium at a fast breeder reactor leaks into a purification cabin, ruining a number of valves and operating systems

Table 2. List of nuclear accidents around the world

DATE	LOCATION	DESCRIPTION
January 21, 1969	Lucens reactor, Vaud,Switzerland	On January 21, 1969, it suffered a loss-of-coolant accident, leading to a partial core meltdown and massive radioactive contamination of the cavern, which was then sealed.
February 22, 1977	Jaslovské Bohunice,Czechoslovakia	Severe corrosion of reactor and release of radioactivity into the plant area, necessitating total decommission
March 28, 1979	Three Mile Island,Pennsylvania, United States	Loss of coolant and partial core meltdown due to operator errors. There is a small release of radioactive gases. See also Three Mile Island accident health effects.
May 4, 1986	Hamm-Uentrop, Germany	Experimental THTR-300 reactor releases small amounts of fission products to surrounding area
March 1992	Sosnovyi Bor, Leningrad Oblast, Russia	An accident at the Sosnovy Bor nuclear plant leaked radioactive gases and iodine into the air through a ruptured fuel channel.
February 20, 1996	Waterford, Connecticut,United States	Leaking valve forces shutdown Millstone Nuclear Power Plant Units 1 and 2, multiple equipment failures found
July 25, 2006	Forsmark, Sweden	An electrical fault at Forsmark Nuclear Power Plant caused one reactor to be shut down

1.2 OUTLINE OF THE PROJECT

Chapter 1 gives a brief introduction about the need of safety from nuclear accidents and introduces about the objectives of the project. Chapter 2 introduces the three special properties that can help predict the nuclear leakages. The state of art of the three special properties is discussed in Chapter 3. In Chapter 4, the method of fabrication and calibration of probes is summarized. Chapter 5 deals with laboratory simulation test and the results obtained are summarized in Chapter 6.

CHAPTER 2

SPECIAL SOIL PROPERTIES

2.1 INTRODUCTION

The characteristics of soils are generally variable and may change sharply within limited distances. It is very important to have idea about the geological conditions and geotechnical properties of the soil, as well as knowledge about the behaviour and the stresses developed in the foundation soil. The primary objective of a subsoil investigation is to determine stratigraphy and physical properties of soils underlying the site so that a safe and an economic foundation may be designed for the structure.

With reference to the problem addressed in chapter 1, besides the traditional in-situ and laboratory tests (Table 3 and Table 4) to determine the soil properties there are some special tests required to be done to determine the soil thermal and electrical characteristics. Estimating thermal resistivity and electrical resistivity of soil gives us some idea about the soil thermal and electrical characteristics. These soil properties need to be determined particularly for nuclear waste disposal facilities, construction of buried pipes, high voltage cables in the ground, corrosion of pipes, grounding establishment, large region surface soil moisture estimates are important for both hydrologic modelling and remote sensing applications. The uses of the above three properties are explained in detail in section 2.3.

2.2 TRADITIONAL METHODS OF TESTS

Table 3. Field and laboratory testing to address some geotechnical issues:

GEOTECHNICAL ISSUES	ENGINEERING EVALUATION	FIELD TESTING	LABORATORY TESTING
Foundations	bearing capacity, settlement (magnitude & rate), shrink/swell of foundation soils (natural soils or embankment fill)	vane shear test, SPT (granular soils), CPT, nuclear density, plate load testing	1-D Oedometer tests, direct shear tests, triaxial tests, grain size distribution, Atterberg Limits, moisture content, unit weight, organic content, collapse/swell potential tests.
Embankment and Embankment Foundation	settlement (magnitude & rate), bearing capacity, slope stability, lateral pressure, internal stability, borrow source evaluation	nuclear density, plate load test, CPT,SPT (granular soils), Dilatometer, vane shear, rock coring (RQD)	1-D Oedometer, triaxial tests, direct shear tests, grain size distribution, Atterberg Limits, organic content, moisture-density relationship, hydraulic conductivity, shrink/swell

Table 4. Lists laboratory of tests done of soils and their applicability.

Test	Procedure	Applicable Soil Types	Applicable Soil Properties	Limitations / Remarks
Moisture Content	Dry soil in oven at 100 + 5 ^{0}C Gravel, sand,	Gravel, sand, silt, clay, peat	e_o, γ	Simple index test for all
Unit Weight and Density	Extract a tube sample; measure dimensions and weight;	Soils where undisturbed samples can be taken, i.e., silt, clay, peat	γ_{tot}, γ_{dry}, ρ_{tot}, ρ_{dry}, σ_{vo}	Not appropriate for clean granular materials where undisturbed sampling is not possible. Very useful index test.
Atterberg Limits LL, PL, PI, SL, LI	LL – Moisture content associated with failure at 25 blows of specimen in Casagrande cup PL – Moisture content associated with crumbling of rolled soil at 3.2 mm	Clays, silts, peat; silty and clayey sands to determine whether SM or SC	Soil classification	Not appropriate in nonplastic granular soil. Recommended for all plastic materials
Mechanical Sieve	Place air dry material on a series of successively smaller screens of known opening size and vibrate to separate particles of a specific equivalent diameter	Gravel, sand, silt	Soil classification	Not appropriate for clay soils. Useful, particularly in clean and dirty granular materials
Hydrometer	Allow particles to settle, and measure specific gravity of the solution with time.	Fine sand, silt, clay	Soil classification	Helpful to assess relative quantity of silt and clay
Specific Gravity	The volume of a known mass of soil is compared to the known volume of water in a calibrated pyncnometer	Sand, silt, clay, peat	Used in calculation of e_o	Particularly helpful in cases where unusual solid minerals are encountered
Organic Content	After performing a moisture content test at 110 ^{o}C, the sample is ignited in a muffle furnace at 440 ^{o}C to measure the ash content.	All soil types where organic matter is suspected to be a concern	Not related to any specific performance parameters, but samples high in organic content will likely have high compressibility	Recommended on all soils suspected to contain organic materials

Symbols used

e_o: in-situ void ratio, γ: unit weight, γ_{tot}: total unit weight, γ_{dry}: dry unit weight, ρ_{tot}: total density, ρ_{dry}: dry density, σ_{vo}: total vertical stress

2.3 USES OF THE SPECIAL PROPERTIES

2.3.1 Moisture content

Optimum water content in the soil causes some cohesion, helps to control dust, and allows easy compaction effort. Determination of the optimum moisture content helps us to find out maximum dry density which gives an idea about the bearing capacity, porosity and permeability of the soil. Most physical and chemical properties of soil vary with moisture content. Measurement of soil water content is needed in every type of soil study. Hydrology, agrology, plant science and civil engineering all require soil moisture data.

2.3.2. Thermal resistivity of soil

Knowledge about soil thermal resistivity is becoming increasingly critical in the design of cable and underground power transmission and distribution systems. It is because flow of electricity in a conductor generates heat. Resistance to the dissipation of heat flow between the cable and the surrounding soil causes the cable temperature to rise. If the rise in temperature is within the design range of the cable, then the underground cable is safe but temperatures above the design temperature can cause catastrophic damage. A fatal accident occurred when cable temperatures became too high, as was the case in Auckland, NZ in 1998. Since the soil is in the heat flow path between the cables, therefore thermal resistance, soil thermal properties are an important part of the overall design.

Accurate prediction of soil thermal resistivity is of prime importance in the numerical simulation of heat transmission through soils. These numerical simulations can be incorporated into computer models which can find a wide variety of applications.

Soil thermal resistivity estimation methods will facilitate the efficient design of ground source heat pump system. The geothermal or ground-source heat pump (GHP) has been shown to be a very efficient method of providing heating and cooling for buildings compared to an air-source heat pump. GHPs exchange (reject or extract) heat with the earth by circulating water, rather than circulating outside air. The temperature of water entering a GHP is generally cooler than that of outdoor air when cooling is required and warmer than that of outdoor air when heating is required. Soil thermal resistivity estimation methods can provide accurate estimates of thermal energy transfer between the surrounding soil and the earth loop heat exchanger. (Hart and Whiddon 1984). Thus we will be able to select proper back fill materials and can accordingly optimize the moisture content required in the backfill. In addition, these estimation methods will assist in assessing the effects of berms on the heat loss from thermal energy storage tanks (Rosen and Hooper 1989).

2.3.3. Electrical resistivity of soil

In highly industrialized areas, due to the metallic infrastructure, surface based electrical resistivity characterization and monitoring is of significant importance. So it is extremely important for a geotechnical engineer to obtain a clear picture of the subsurface electrical properties. Electrical resistivity prediction is also required for nuclear waste disposal facilities, construction of buried pipes, high voltage cables in the ground, corrosion of pipes and grounding establishment.

CHAPTER 3

LITERATURE REVIEW

Though there are some literatures available on predicting nuclear leakages by observing the abnormal changes in moisture content of soil but predicting nuclear leakage by estimating thermal resistivity, electrical resistivity and moisture content of soil is a new concept. Besides, soil thermal and electrical properties are complex properties and both depend on the moisture quantity, soil type and minerals present in the soil, etc. A brief review of the existing method to determine soil thermal resistivity, electrical resistivity and moisture content is described below

3.1 Thermal Resistivity Measuring Techniques

Though there are very few literatures regarding thermal resistivity of soil, many correlations for estimating soil thermal conductivity have been proposed in literature. These correlations are complex and difficult to understand. Kersten (1949), Gemant (1952), De Vries (1952), Van Rooyen and Winterkorn (1957), Johansen (1975), and many others, have developed correlations for soil thermal conductivity. Each method is limited to only certain soil types and that too under specific conditions.

Kersten (1949) tested many soil types and produced equations for frozen and unfrozen silt-clay soils and sandy soils. Gemant (1952) correlation was based on the assumption that idealized soil particles made contact only at their apexes and thee water that is collected around these contact points form a thermal bridge. He also assumed that the heat flow took place in vertically upward direction. The correlation given by De Vries (1952) assumed that soil is a two phase material. De Vries method is applicable to unfrozen coarse grained soils with saturation levels between 10% to 20%. Van Rooyen's correlation (1957), based on experiment conducted on different types of sand and gravel, and is limited to unfrozen sand and gravel with saturation levels between 1.5% to 10%. Johansen's method is suitable for calculating soil thermal conductivity of both coarse and fine-grained soils in the frozen and unfrozen states. However, it is limited to saturations greater than 20%.

There are two methods employed to estimate the thermal resistivity of the soil:

1) The steady state method

2) The transient method

3.1.1 The steady state method:

In this method a temperature gradient is maintained in the soil within the probes. When the temperature gets stabilized, the power required to maintain the temperature gradient is noted and then the following equation is used to determine the thermal conductivity (reciprocal of thermal resistivity) of the soil sample:

$$k = \frac{Q}{A}\frac{\Delta X}{\Delta T} \tag{1}$$

where Q is the electric power supplied, ΔX is the length of the sample, A is cross-sectional area of the sample and ΔT is the time difference to attend the stabilized temperature. But there were some drawbacks in this method. The time required for achieving the stabilized temperature may lead to migration of moisture from the hot end to the cold end and thus may result in inaccurate measurement of thermal resistivity of the soil. (Kersten 1949, Penner et al. 1975, Farouki 1986).

3.1.2 The transient method:

The method is based on the fact that the rate of increase in temperature of heated body buried under a material depends upon the thermal coefficient of the material in which it is buried. This method involves inserting a thin thermal probe into the soil sample and applying constant electric power to the thermal probe. The variation in probe temperature over time is noted which is used to estimate the thermal conductivity of the soil sample by using the following equation:

$$k = \frac{2.303Q}{4\pi\Delta\theta}\log\frac{t_2}{t_1} \tag{2}$$

where Q is heat input per unit length, $\Delta\theta$ is the rise in temperature, t_1 and t_2 are two different periods of time, k is the thermal conductivity (reciprocal of thermal resistivity). Transient method of estimating thermal conductivity has been employed by many researchers. It has been noticed that this method is quite convenient and can be adopted for accurate measurement. (Hooper and Lepper, 1950).

There is very little information available to estimate the in-situ value of soil thermal resistivity except a comprehensive report given by the Insulated Conductors Committee of the AIEE (now the IEEE) published in 1960. The guidelines provided in the report were for the laying of underground cables. No specific guidelines are proposed for detecting the nuclear leaks. The report consisted of information that was known at that time and identified areas for future development to build up practical guidelines a more comprehensive knowledge for estimating soil thermal characteristics. Since that time there have been only limited studies to obtain a better understanding of these characteristics. The in-situ measurements are still done using the guidelines provided in IEEE 442-1981 and ASTM 5334-00.

3.2 Electrical Resistivity Measuring Techniques

Most common measuring techniques of electrical resistivity are the Wenner (4-Pin) Array and the Schlumberger Array.

3.2.1 Wenner array

Using the Wenner method, the apparent soil resistivity value is:

$$\rho = \frac{4.\pi.a.R}{1 + \frac{2.a}{\sqrt{a^2 + 4b^2}} - \frac{a}{\sqrt{a^2 + b^2}}} \tag{3}$$

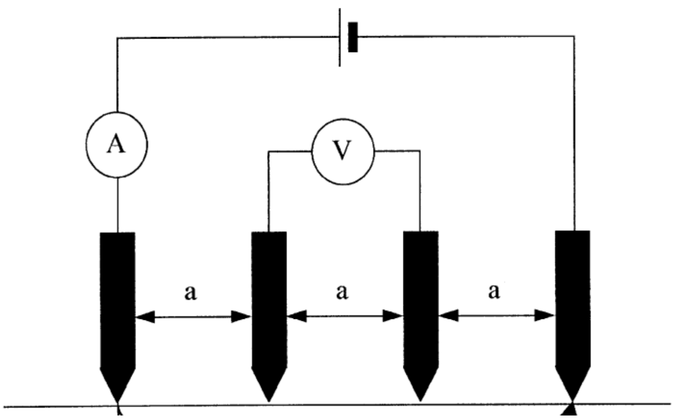


Figure 1 Wenner array configuration

where ρ is the measured apparent soil resistivity (Ω. m), *'a'* is the electrode spacing (m), b= depth of electrodes (m), R is the resistance obtained which is equal to V/I.

3.2.2 Schlumberger Array:

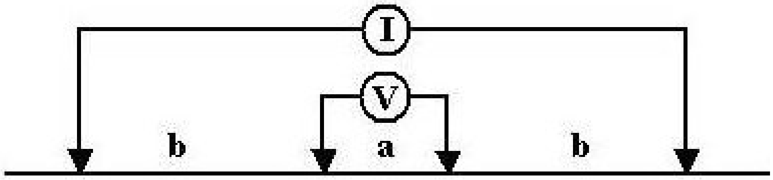


Figure 2. Schlumberger array configuration

In the Schlumberger method the distance between the voltage probes is *a* and the distances from voltage probe and current probe are *b.* Using the Schlumberger method, if depth of probe is small compared to a and b, and b>2a, the apparent soil resistivity value is

$$\rho = \pi \frac{b.(b+a)}{a} R \qquad (4)$$

ρ is the measured apparent soil resistivity (Ω. m), R is the resistance obtained which is equal to V/I.

ASTM G187 - 12a standard test method for measurement of soil resistivity using the two-electrode soil box method and ASTM G57 - 06(2012) standard test method for field measurement of soil resistivity using the wenner four-electrode method are the two well established guidelines for measuring the electrical resistivity of soil. The main purpose of this guide is to provide sufficient information to enable the user to select useful commercial test equipment, or to manufacture equipment which is not readily available on the market, and to make meaningful resistivity measurements with this equipment. This test method covers the equipment and procedures for the field measurement of soil resistivity, both in situ and for samples removed from the ground, for use in the control of corrosion of buried structures.

3.3 Moisture content measuring techniques

There are various methods of measuring the moisture content in the soil but the techniques reviewed here involve the use of gravimetric, nuclear, electromagnetic and tensiometric methods of measuring soil moisture content.

3.3.1 Oven-drying technique

The oven-drying technique is the most widely used gravimetric methods for measuring soil moisture. This method is a destructive test and requires removing a soil sample from the field. It is the standard method that forms the calibration for all other soil moisture determination techniques. This method ensures accurate measurements but it requires 24 hours of drying time. So it is impossible to obtain soil moisture at the same point in a later date.

3.3.2 Neutron scattering

Neutron scattering is widely used for estimating volumetric water content. This method is based on the principle that, fast moving neutrons when allowed to pass through the soil, gets thermalized or slowed down by hydrogen atoms in the soil. Since the main component of water is the hydrogen atoms, the proportion of thermalized neutrons is correlated to obtain soil water content. This method has the advantage of measuring a large volume of soil, and also allows scanning at several depths so that a profile of moisture distribution is obtained. However, it also has a number of disadvantages like radiation hazard, the high cost of the instrument, insensitiveness to small variations in moisture content at different points due to soil density variations, insensitiveness near the soil surface, which may cause an error rate of up to 15 percent.

Gamma ray attenuation method

The gamma ray attenuation method is another radioactive technique that is used to determine soil moisture content. This method is based on the scattering of gamma rays and the variation in absorption of gamma rays obtained due to different soil density. Since the density of soil changes with increases or decreases in moisture, the moisture content is determined from this density change. This method is restricted to soil thickness of less than one inch. It is costly and difficult to use and large errors occur when used in highly stratified soils.

3.3.3 Nuclear magnetic response

Nuclear magnetic response also measures the volumetric moisture content in which the water in the soil is subjected to both static and oscillating magnetic field at right angles to each other. This method has same shortcomings as that of neutron scattering method.

3.3.4 Resistive sensor

The electrical resistivity soil depends on moisture content. This forms the basis for the resistive sensor. The major drawback of resistive sensors is that the absolute value of soil resistivity depends on both ion concentrations as well as on moisture concentration. Therefore, careful calibration is required for this technique.

3.3.4 Time-domain reflectometer

Time-domain reflectometer (TDR) involves propagation of electromagnetic (EM) waves or signals into the soil. Propagation constants for EM waves in soil, such as velocity and attenuation are affected by soil properties, its electrical conductivity and water content. The dielectric constant, measured by TDR, provides accurate measurement of this soil water content but this technique involves high precision instruments that are very costly.

3.3.5 Hygrometric technique

Since thermal properties of a porous medium depend on moisture content, soil temperature can be used to indicate moisture content in the soil. Electrical resistance hygrometers utilize aluminium oxide, thermal principles, electrolysis, and white hydrosol to measure relative humidity. The resistance measured by the resistive element is a function of relative humidity which is correlated to obtain the moisture content in the soil. This process also has some major drawbacks like the sensing element (same as the resistive element) deteriorates with when comes in contact with the soil components and each sensing element be tested requires special calibration.

3.3.6 Tensiometric Technique

Capillary tension in the soil is measured by the use of tensiometer which is correlated to obtain the moisture content in the soil. The main disadvantage of the tensiometer is the range in which it functions. It functions only from zero to about 0.8 bars, which is a small part of the entire range of available water. The lower moisture limit required by agriculturist for the good growth of most crops is beyond the tensiometer range.

CHAPTER 4
METHODOLOGY

This chapter describes the working principle, method of fabrication and calibration of each probe (i.e. thermal, electrical and soil moisture probe) in detail. The results obtained while calibrating the probes and validation of the thermal and electrical probes using fly ash and pond ash are also presented at the end.

4.1 Working Principle of the thermal probe used in the present study:

The thermal probe used in the present study is based on transient method of estimating thermal resistivity. When the thermal probe is inserted into the soil and a constant power is supplied to heat the nichrome wire, the rise in temperature depends upon the soil conductivity and duration of heating. The rise in temperature is estimated using the Equation (2).The plot of temperature over time shows a straight line portion of slope s which is given by the following expression

$$s = \frac{Q}{4\pi k} = \frac{QR}{4\pi} \tag{5}$$

but we know that $$Q = i^2 \xi \tag{6}$$

where i is the current passed to supply power Q to the probe and ξ is the resistance of the nichrome wire per metre. Combining Equation (5) and Equation (6) resistivity (R) comes out to be

$$R = \frac{4\pi}{2.303 i^2 \xi} \times s \tag{7}$$

4.1.1 Fabrication of thermal probe:

The laboratory thermal probe used in the present study has the following components and the details are shown in Figure 3:

- A hollow copper tube of 140 mm length and external of 2.5 mm.
- Nichrome heater wire is used for heating the probe by passing current through it. ξ of the nichrome wire used for the lab thermal probe is $10 \cdot \Omega m^{-1}$

➢ Magnesium Oxide (MgO) of very low resistance ($150\times10^{-6}\ \Omega$) is used as a filler material. It is provided so as to ensure uniform dissipation of the heat generated.

➢ A thermocouple is provided, on the inner surface of the tube, at distances of 65mm, from the bottom of the probe, to measure temperature of the probe.

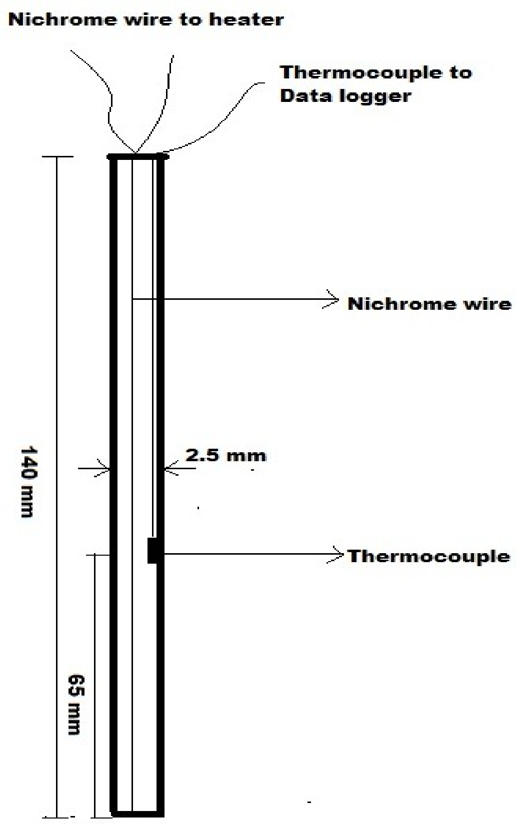


Figure 3. Details of the thermal probe (Naidu and Singh, 2004)

4.1.2 Calibration of the probe:

To check proper and efficient functioning of the thermal probe, standard glycerol was used. The properties of the glycerol are presented in Table 5:

Table 5. Properties of glycerol (Naidu and Singh, 2004)

PROPERTY	VALUE
Weight (g) per ml., at 20^{0}C	1.255-1.260
Neutrality	Neutral to litmus
Thermal resistivity	3.48 m.^{o}C.W^{-1}

‘

The steps followed for calibration is explained detail below (Naidu and Singh, 2004):

1. A glass tube sufficient enough to hold the thermal probe was taken, so that it does not touch the walls of the glass tube was taken. It was filled with glycerol.
2. The thermal probe was inserted into the glass tube and was allowed to gain thermal equilibrium with the glycerol.
3. The nichrome wires of the thermal probe were connected to a data logger to read the temperature.
4. A controlled power supply of 12V-24V DC voltage (present study 12 V DC voltage was adopted) was switched on.
5. Then probe temperature was recorded (by data logger) at different intervals of time till no appreciable change in temperature was noticed.

Table showing temperature recorded at different temperature is presented in Table 6. Using the recorded data, temperature vs. time and temperature vs. log (time) relationships were plotted, as shown in Figure 5**.** The value of ***s*** for the thermal probe for three trials was found to be equal to 11.21, 14.20, and 16. An average *s* value of 13.80 was used for determining the thermal resistivity of the glycerol (obtained from Equation (7)), which was found to be equal to 3.44 $m \cdot K \cdot W^{-1}$. The computed thermal resistivity value is within 3% of the accepted value for glycerol (3.48 $m \cdot K \cdot W^{-1}$). This indicates that the fabricated thermal probe works very efficiently and hence it can be used for estimating thermal resistivity of various soils.

The probe was further used to compare the variation in thermal resistivity at optimum moisture content (OMC) and at dry state in fly ash and pond ash which is shown in Figure 6 and Figure 7 respectively. For fly ash, at dry state thermal resistivity obtained was 4.11 m. K. W^{-1} but it decreased to 4.72 m. K. W^{-1} at OMC. Similarly, for pond ash, at dry state thermal resistivity obtained was 7.76 m. K. W^{-1} but it decreased to 6.10 m. K.W^{-1} at OMC. The decrease in thermal resistivity is due to the fact that at OMC maximum dry density is obtained. So as the density increased, particles came closer and there was increase in contact between the particles as a result thermal conductivity increased and resistivity decreased.

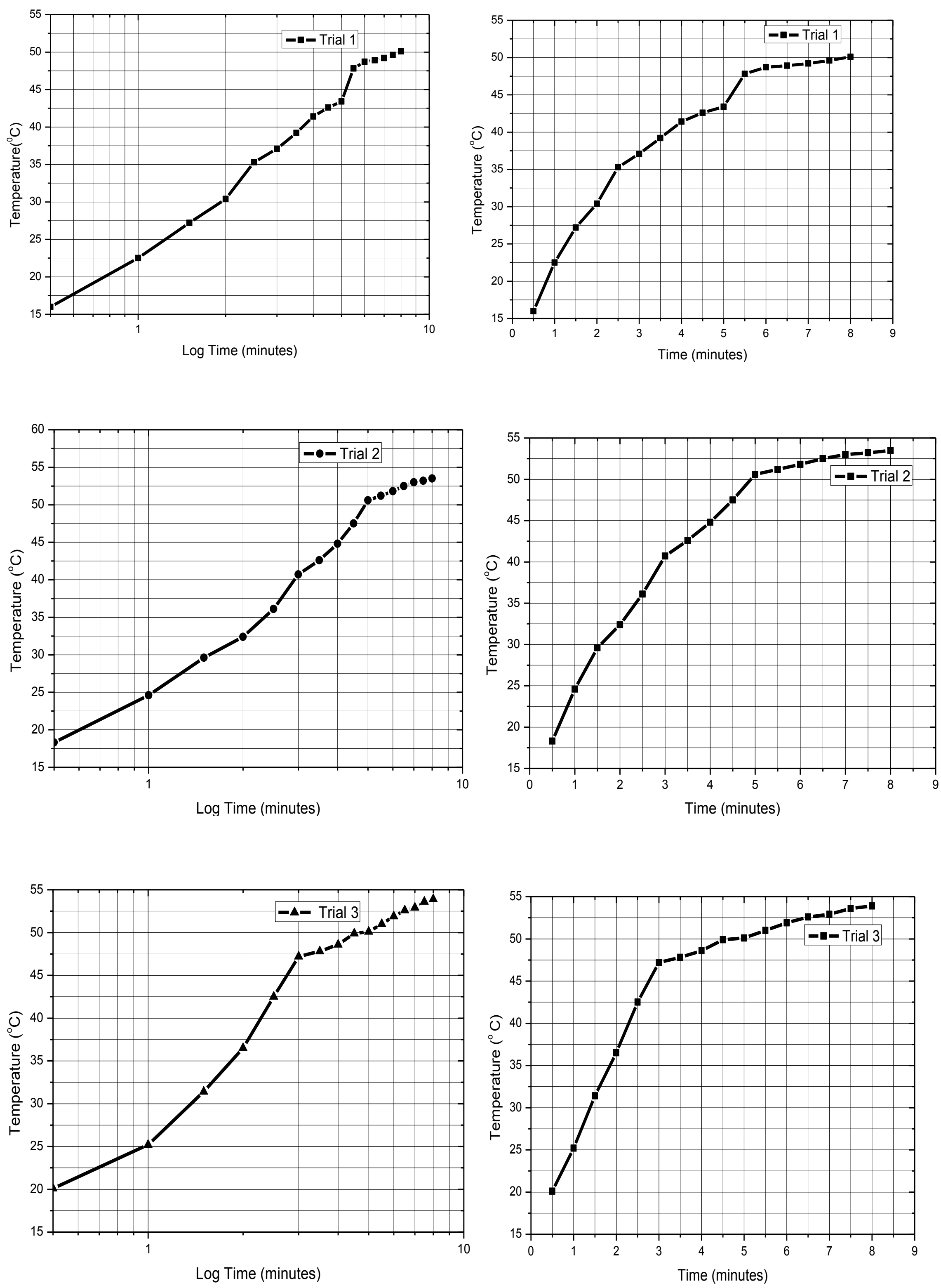


Figure 4. Temperature vs Time (log scale) & Temperature vs Time for glycerol for three trials

Table 6. Results obtained while calibrating thermal probe using glycerol. (Voltage=12V current=1.48A)

Trial 1		Trial 2		Trial 3	
Time elapsed(min)	Temperature recorded (^oC)	Time elapsed(min)	Temperature recorded (^oC)	Time elapsed(min)	Temperature recorded (^oC)
0.5	16	0.5	18.3	0.5	20.1
1	22.5	1	24.6	1	25.2
1.5	27.2	1.5	29.6	1.5	31.4
2	30.4	2	32.4	2	36.5
2.5	35.3	2.5	36.1	2.5	42.5
3	37.1	3	40.7	3	47.2
3.5	39.2	3.5	42.6	3.5	47.8
4	41.4	4	44.8	4	48.6
4.5	42.6	4.5	47.5	4.5	49.9
5	43.4	5	50.6	5	50.1
5.5	47.8	5.5	51.2	5.5	51
6	48.7	6	51.8	6	51.9
6.5	48.9	6.5	52.5	6.5	52.6
7	49.2	7	53	7	52.9
7.5	49.6	7.5	53.2	7.5	53.6
8	50.1	8	53.5	8	53.9

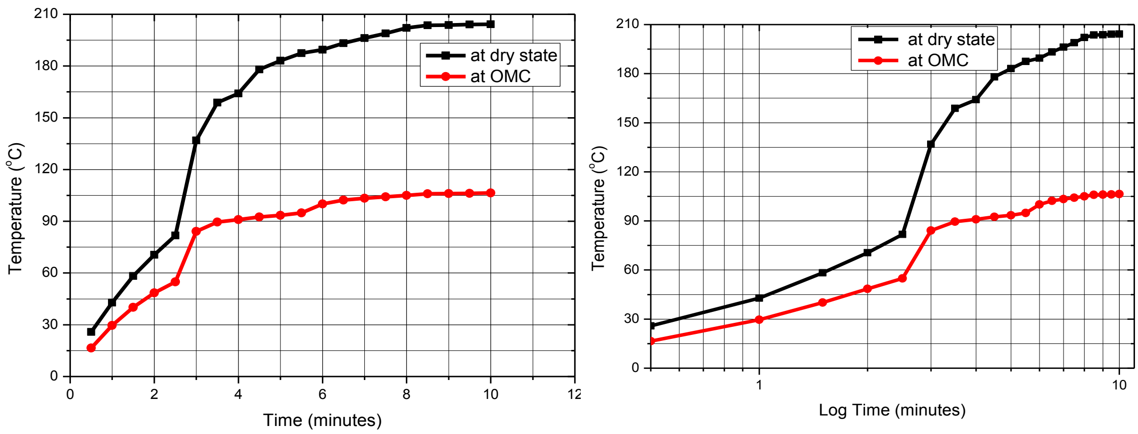


Figure 5. Temperature vs Time (log scale) & Temperature vs Time for Fly Ash

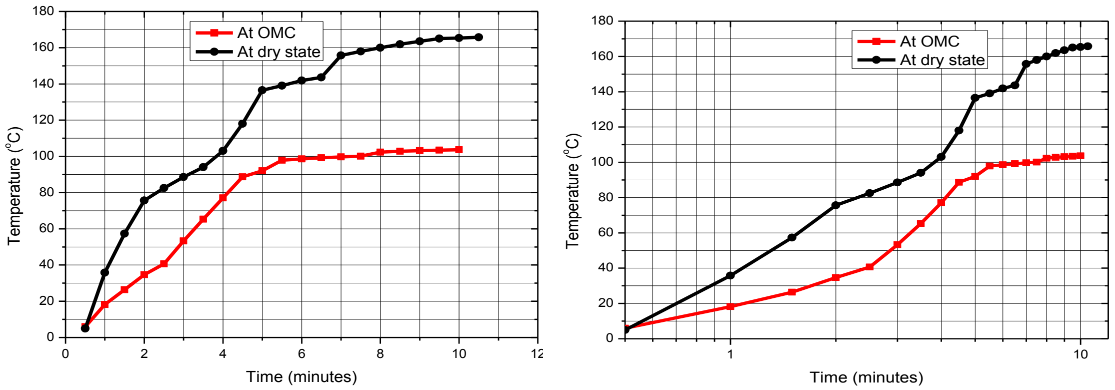


Figure 6. Temperature vs Time (log scale) & Temperature vs Time for pond Ash

4.2 Working principle of the electrical probe used in present study:

The electrical resistivity is estimated from the electrical resistance which is obtained by using the Ohm's law. A constant source of voltage 50 V AC power supply, which operates at 50 Hz, was used in this study. Detail guidelines are presented by Abu- Hassanein (1994) and Abu-Hassanein et al. (1996). The current *I* passing through the medium is measured using an ammeter or digital multimeter. The voltage drop V is measured across another two electrodes using a voltmeter. Figure 7 shows the electrical probe showcasing the four different electrodes which is explained in detail in the fabrication of electrical probe. The resistance *R* offered by the medium can be expressed as:

$$R = \frac{V}{I} \tag{8}$$

The resistance (R) obtained can be correlated with electrical resistivity (ρ) by using a parameter 'a' which is a function of probe geometry (Naidu and Singh, 2004).

$$\rho = aR \tag{9}$$

This parameter can be used for calibrating the electrical probe, the details of which is explained in section 4.2.2.

4.2.1 Fabrication of electrical probe:

The components involved in fabricating the electrical probe is described below and the figure showing the details of electrical probe is shown in Figure 7.

- The electrical probe consists of an ebonite rod which is 140 mm long and has an external diameter of 9mm.
- Four copper strips (or strips made of stainless steel) of 10mm width are wound around the ebonite rod. The extreme two are the current electrodes where as the middle two copper strips act as voltage electrodes. The distance between the current and voltage electrode is kept 10 mm.
- The end of the probe can be either sharpened or a conical stainless steel material of 20mm length can be attached.

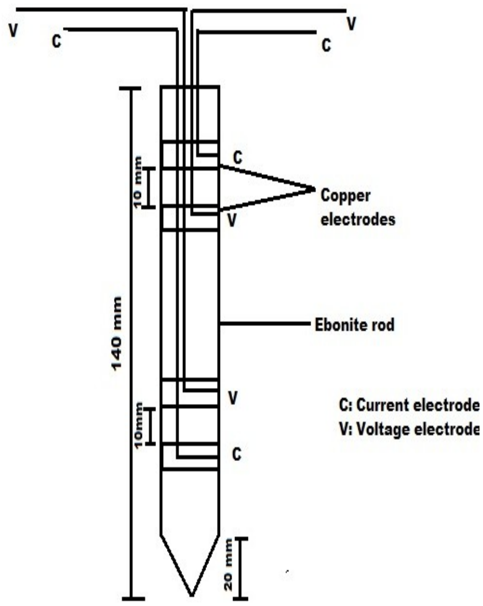


Figure 7. Details of electrical probe (Sreedep et. al, 2004)

4.2.2 Calibration of the probe:

The parameter ‘a’ discussed before is estimated by correlating the electrical resistance of standard sodium chloride and potassium chloride solutions of known electrical resistivity. Detail procedure is explained below:

1. 1M solution of NaCl was taken (dissolving 58.44g of NaCl in 1L of distilled water) to check its electrical conductivity.
2. The electrical conductivity measured was converted to 25 ^{o}C. The conductivity measured was divided by one to get the electrical resistivity.
3. Then with the help of the fabricated electrical probe, electrical resistance of the solution was found out using Equation (8).
4. Similarly, the electrical resistance and resistivity of different molar solutions of NaCl and KCl were recorded.
5. The points were plotted on the graph and a best fit line passing through the origin was plotted which gives the value of ‘a’.

The calibration graph obtained in the present study is shown in the Figure 8 for the sake of completeness. The value of ‘a’ was found to be 0.0630 with a standard error of 0.14%.

The electric probe was then used to study the variation in electric resistivity with moisture content for fly ash and pond ash. A known volume of sample was taken in a mould and the probe was inserted into it. Then with varying amount of water content, the resistance was calculated and the resultant resistivity was computed using the calibration graph shown in Figure 8. The variation of electrical resistivity with moisture content in fly ash and pond ash is shown in Figure 9. With the increase in moisture content there was gradual decrease in electrical resistivity which gradually became constant after a certain limit. Electrical resistivity couldn't be obtained for moisture content less than 30% because the current flowing was too small to measure in the ammeter.

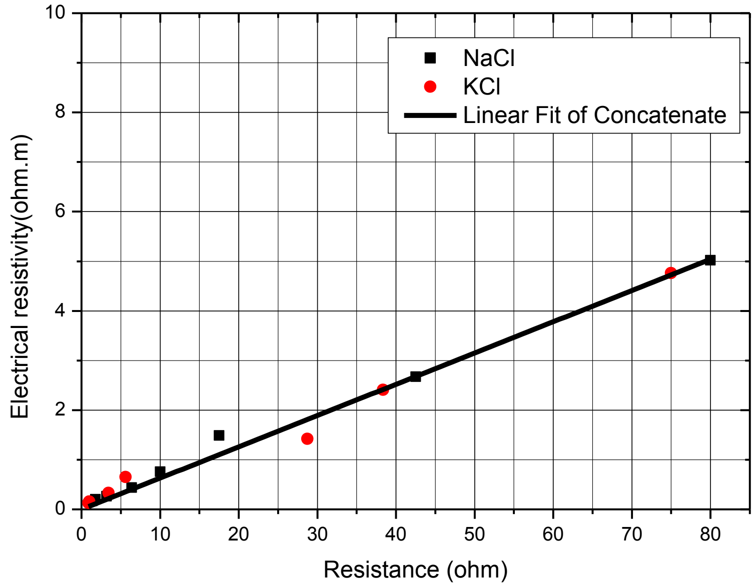


Figure 8. Determination of parameter 'a

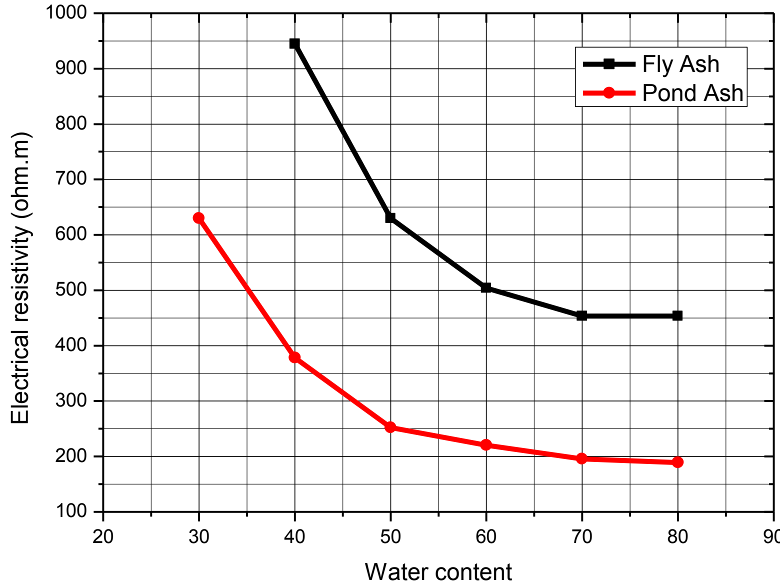


Figure 9. Comparison of electrical resistivity of fly ash and pond ash at different water content

4.3 Working principle of the moisture content measurement probe used in present study:

The dielectric constant of a dry material consisting of soil particles and air is different from the dielectric constant of the soil containing moisture. (Atkins et. al, 1998). This concept is used in measuring the soil moisture. Even small amount of water in a soil can cause the dielectric constant of the resultant soil–water–air mixture to change. So the moisture content in the soil can be efficiently found out by determining the dielectric constant of the soil by using Equation (10). Dielectric constant is determined by measuring the capacitance of the soil. The capacitance of the soil sample is measured using LCR meter attached the soil moisture probe. The mathematical calculations involved in estimating the dielectric constant from the capacitance is described in section 4.3.2.

4.3.1 Fabrication of soil moisture probe:

The fabrication detail is given below and details of the probe are shown in Figure 10.

- The soil moisture probe consisted of two copper plates of 140 mm long, 10 mm wide and 2mm thickness.
- The two copper plates were kept 51 mm apart.
- The end of the plates were sharpened so that it can easily get inserted in the soil

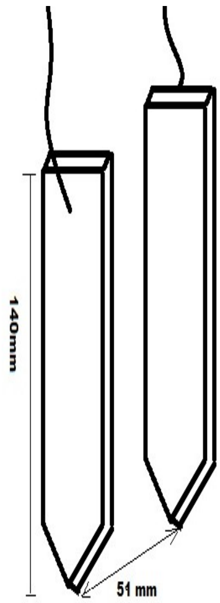


Figure 10. Soil Moisture Probe (not drawn to scale)

4.3.2 Mathematical calculations:

1. Volumetric Moisture content (θ) is given by *Topp et al.'s equation*:

$$\theta = (-5.3\times10^{-3}) + (2.93\times10^{-2})\varepsilon - (5.5\times10^{-4})\varepsilon^2 + (4.3\times10^{-6})\varepsilon^3 \quad (10)$$

where ε dielectric constant of the soil.

2. Dielectric constant of the soil is equal to ratio of capacitance of soil to capacitance of air $(\frac{C_{soil}}{C_{air}})$ (11)

3. C_{air} (capacitance of air) $= \frac{C_{water}}{K_{water}}$ (12)

4. K_{water} is the dielectric constant of water. The values of K_{water} varies with temperature. The values at different temperature are tabulated in Table 7.

Table 7. Dielectric constant of water (Atkins et. al, 1998)

Temperature *(°C)*	**K**	**Temperature *(°C)***	**K**
0	88.00	40	73.28
5	86.40	45	71.59
10	84.11	50	69.94
15	82.22	60	66.74
20	80.36	70	63.68
25	78.54	80	60.78
30	76.75	90	57.98
35	75.00	100	55.33

Sample calculation for estimating $C_{air} = \frac{C_{water}}{K_{water}}$

K_{water} = 78.54 (at 25 ^{o}C)

C_{water} observed by the moisture probe is 243.47μF

$C_{air} = \frac{243.47}{78.54} = 3.1\ \mu F$

CHAPTER 5

LABORATORY SIMULATION

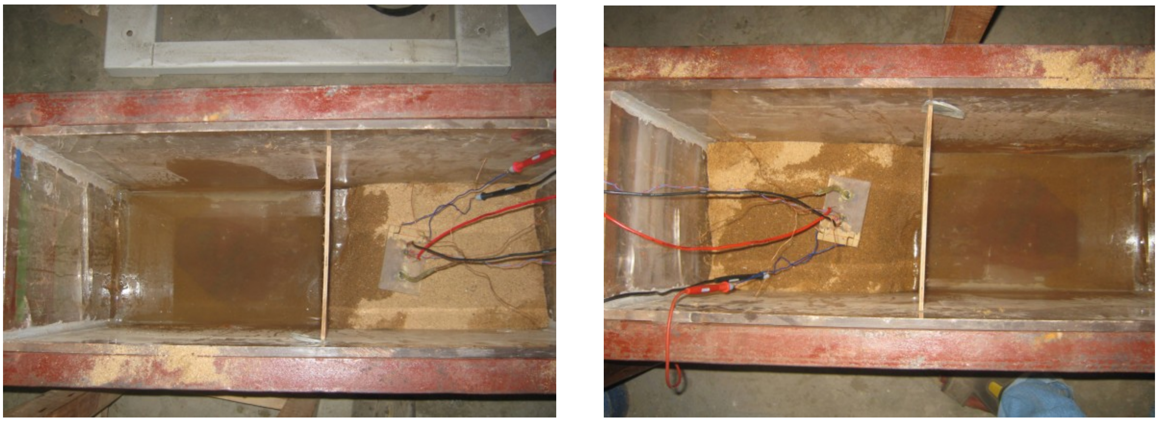
To monitor leak from a nuclear containment, the leak was simulated by injecting high conductivity fluid in a tank. High conductivity fluid consisted of sodium thiosulphate pentahydrate. The simulated waste consisted of a 25% (by volume) sodium thiosulphate pentahydrate solution with a specific gravity of approximately 1.138 at a temperature of 23.1^{o}C. The reason for the use of the above chemical is it has electrical and thermal properties similar to that of nuclear wastes stored in storage tanks. The tank used for the simulation of leakage was of dimension 700mm x 250 mm x 500mm made of perspex sheet shown in Figure 11(a), so that there is no reaction between the simulated waste and the tank material.

(a) **(b)**

Figure 11. (a) The Perspex tank. (b) Experimental set up

5.1 Experimental Procedure:

1. To observe the changes in soil property quickly due to leakage, dry sand was used. Dry sand has more permeability than the clay. Due to better permeability, the change in soil properties can be observed quickly due to the simulated leakage.
2. The tank was divided into two halves by a separator (made of ply wood) to have the simulated waste liquid on one side and the sand on the other side. Holes were made on the ply wood to force the leakage. The experimental setup is shown in Figure 11 (b)
3. The multifunctional instrument was inserted into the sandy soil. Proper connections were made to the probes so that the readings can be taken easily and simultaneously
4. From the other side of the separator the simulated waste was poured gradually.
5. Thermal resistivity, electrical resistivity and moisture content were calculated in the similar way as described in section 4.1.2, 4.2.2, 4.3.2 respectively.
6. The variation of temperature, resistance and moisture content were observed and plotted in graph.



(a) **(b)**

Figure 12. (a) Initial Stage of the leakage. (b) Later stage of leakage

CHAPTER 6

RESULTS AND DISCUSSIONS

The experiment was conducted as per the experimental procedure described in chapter 5. To study the variation in the soil thermal and electrical resistivity and moisture content, similar procedure was adopted and the leakage was simulated using normal water. A comparison was made to study the variation in the above properties.

6.1 CHANGES IN THERMAL RESISTIVITY

When the thermal resistivity of the soil (in our case dry sand) was checked, it was seen that the thermal resistivity of the soil decreased after the leakage. The plot showing the change in temperature over time is shown in Figure 13. When computing the thermal resistivity, the value came out to be 4.35 m. k. W^{-1}, while it decreased to 3.66 m. k. W^{-1}.

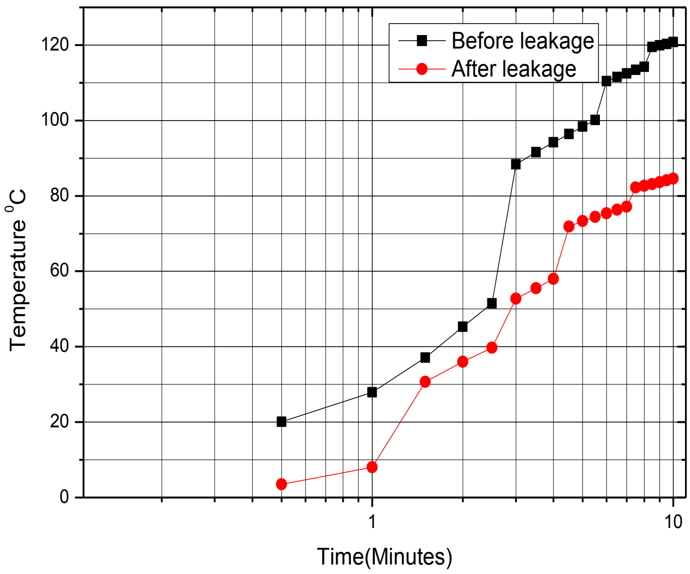
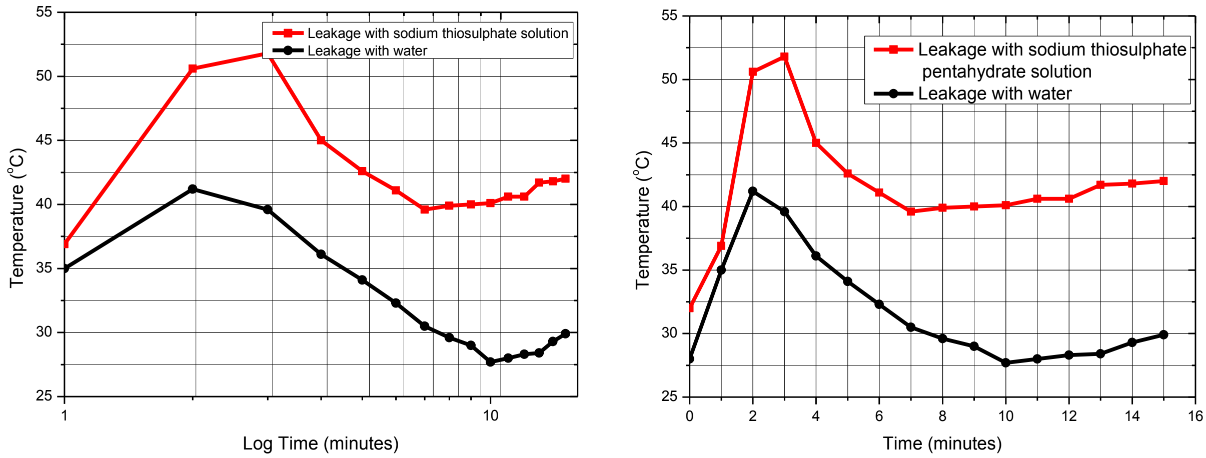


Figure 13 Plot showing variation in temperature before leakage and after leakage with time

The reason for decrease in thermal resistivity can be explained that, as the stimulant liquid filled the voids of the soil, there was better conduction of heat. As a result of which the resistivity decreased.

Another comparison was made to study the behaviour of soil thermal resistivity when there was leakage of sodium thiosulphate pentahydrate and normal water. The plot showing the comparison is shown in Figure 14.



(a) (b)

Figure 14. Plot showing difference in temperature variation due to leakage of sodium thiosulphate pentahydrate and due to leakage of water with time (a) in log scale (b) linear scale

The liquid in both the cases were added at 0 minutes. There was increase temperature observed in both the cases initially. This is due to the probe attached to constant power supply. Then there is a sudden decrease in temperature observed. This is due to, when the probe comes in contact with leakage liquid. Then after the probe attains equilibrium with the leaked surrounding environment, there is steady increase in temperature over time and at this time the resistivity is computed. The resistivity of the soil when simulated with sodium thiosulphate pentahydrate solution came out to be 3.41 m. $K.W^{-1}$ and when simulated with normal water, it came out to be 3.90 m. $K.W^{-1}$. The reason being sodium thiosulphate pentahydrate solution is a better conductive liquid compared to normal water As a result resistivity decreased.

6.2 CHANGES IN ELECTRICAL RESISTIVITY

Similar to the thermal resistivity, a comparative study was made to observe the difference in electric resistivity of soil due to sodium thiosulphate pentahydrate solution (high conductivity fluid) and normal water. The result is plotted in graph and shown in Figure 15.

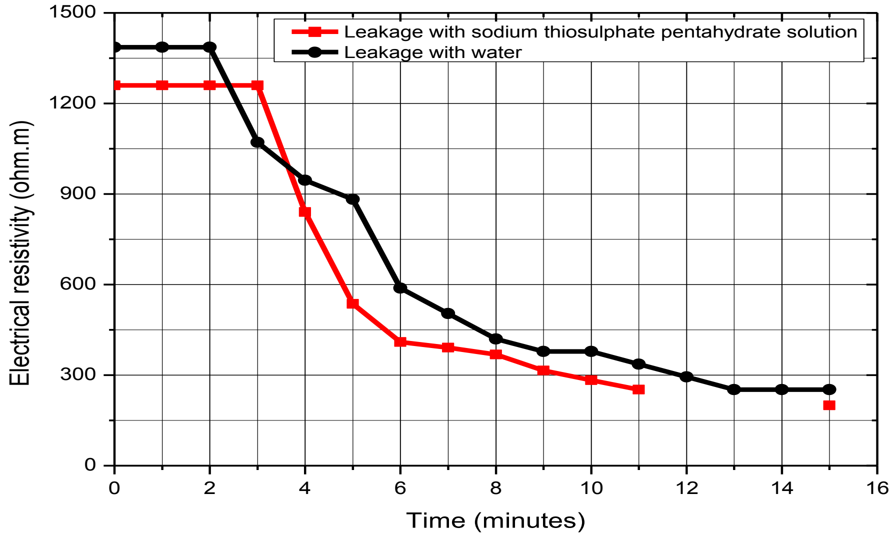


Figure 15. Plot showing variation of electrical resistivity due to leakage of sodium thiosulphate pentahydrate and due to leakage of water with time

The electrical resistivity of the soil with leakage from sodium thiosulphate pentahydrate solution had less resistivity compared to leakage with normal water. Sodium thiosulphate pentahydrate solution increases the ionic concentration in the soil as a result of which the electrical conductivity increases resulting in decrease in electric resistivity.

6.3 CHANGES IN MOISTURE CONTENT

Slight difference was observed in the moisture content in leakage due to both the case. Since the moisture probe used in the present study estimates the dielectric constant of the soil and correlates it with the moisture content, slight difference was observed between the two cases. Figure 16 shows the change in pattern in moisture content due to sodium thiosulphate pentahydrate and normal water.

6.4 CONCLUSION:

The thermal probe developed, when calibrated using standard glycerol showed results which was within 3% of the accepted limits of the glycerol. Similarly the electrical probe which was calibrated using standard sodium chloride and potassium chloride solution was used to estimate the electrical conductivity of fly ash and pond ash at different moisture content. The variation was checked and it was within the range of its value.

The multifunctional instrument developed to predict the change in behavior of soil thermal and electrical properties and also change in moisture content, showed change in thermal resistivity and electrical resistivity, and slight change in moisture content after the leakage was simulated in laboratory using high conductivity fluid (sodium thiosulphate pentahydrate). So this equipment can be used as one of the method to give a preparatory warning from nuclear leakages from nuclear containments.

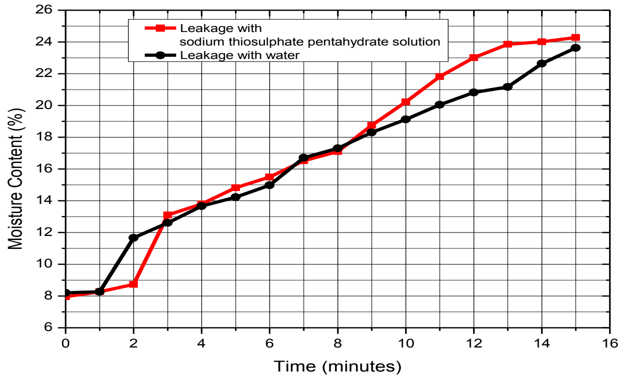


Figure 16. Plot showing variation of moisture content due to leakage of sodium thiosulphate pentahydrate solution

SCOPE FOR FUTURE WORK:

- The probes to be used in field should be of minimum 1 m length.
- There should be arrangement to transmit the field data to the laboratory for enabling real time monitoring
- Figure 17 shows the field probe that is proposed to be fabricated in future.

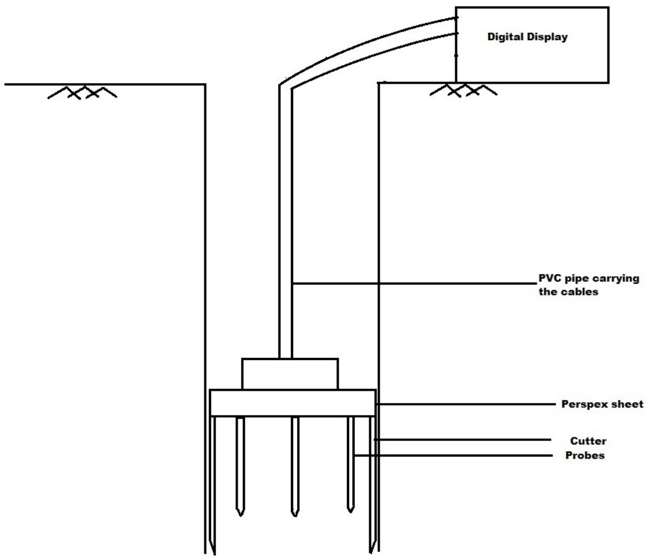


Figure 17. Diagram showing the multifunctional field probe

REFERENCES

[1]. Abu-Hassanein, Z. S. and Benson, C. H., (1994), "*Using Electrical Resistivity for Compaction Control of Compacted Soil Liners*", *Tailings and Mine Waste*, Balkema, Rotterdam, pp. 177–188.

[2]. Abu-Hassanein, Z. S., Benson, C. H., and Blotz., L. R., (1996), "*Electrical Resistivity of Compacted Clays*", *Journal of Geotechnical Engineering*, *ASCE*, Vol. 122, No. 5, pp. 397–408.

[3]. Atkins, R.T., Pangburn, T., Bates, R. E., and Brockett, B. E., (1998), "*Soil Moisture Determinations Using Capacitance Probe Methodology",* Special report, US Army Corps of Engineers®, Cold Regions Research & Engineering Laboratory.

[4]. De Vries, D.A., (1952), The Thermal Conductivity of Soil. *Mededelingen van de Landbouwhogeschool te Wageningen,* 52 (1):1-73, translated by Building Research Station (Library Communication No. 759), England.

[5]. Doughty, C., Nir, A., Tsang, C.F., and Bodvarsson, G.S., (1983), "*Heat Storage in Unsaturated Soils: Initial Theoretical Analysis of Storage Design and Operational Method*." in Proceedings of the International Conference on Subsurface Heat Storage in Theory and Practice, Stockholm.

[6]. Farouki and Omar T., (1986), *Thermal Properties of Soils*. New York: Trans Tech Publications.

[7]. Gemant, A., (1952), "How *to Compute Thermal Soil Conductivities*", Heating, Piping, and Air Conditioning 24 (1):122-123.

[8]. Hart, G.K. and Whiddon, W.I., (1984), "*Ground Source Heat Pump Planning Workshop",* Summary of Proceedings, EPRI Report RP 2033-12. Palo Alto: Electric Power Research Institute.

[9]. Hooper, F.C., Lepper, F.R., (1950), "*Transient heat flow apparatus for the determination of thermal conductivity*", J. Amer. Soc. Heating Ventilating Engrg., 129–140.

[10]. Johansen, O., (1975), "*Thermal Conductivity of Soils*", Ph.D. thesis, Trondheim, Norway, (CRREL Draft Translation 637, 1977) ADA 044002.

[11]. Kavanaugh, S., and K. Rafferty, K., (1997), "*Ground-Source Heat Pumps: Design of Geothermal systems for Commercial and Institutional Buildings",* Atlanta: American Society of Heating, Refrigerating and Air-conditioning Engineers.
[12]. Kersten, M.S., (1949), *Thermal Properties of Soils*. Bulletin 28, Engineering Experiment Station, Minneapolis: University of Minnesota.
[13]. Morgensen, P. 1983. "Fluid to Duct Wall Heat Transfer in Duct System Heat Storages." In *roceedings of the International Conference on Subsurface Heat Storage in Theory and Practice,* Swedish Council for Building Research, June 6–8.
[14]. Naidu A.N. and Singh D.N., (2004), "*Field Probe for Measuring Thermal Resistivity of Soils*", Journal of Geotechnical and Geoenvironmental Engineering, ASCE. 130(2), 213-216
[15]. Penner, E., Johnston, G.H., Goodrich, L.E., (1975), "*Thermal Conductivity Laboratory Studies of Some MacKenzie Highway Soils."* Canadian Geotechnical Journal 12 (3):271-288.
[16]. Rosen, M.A. and Hooper, F.C., (1989), "*A Model for Assessing the Effects of Berms on the Heat Loss from Partially Buried Heat Storage Tanks*." Proceedings of the 9th International Heat Transfer Conference, Jerusalem, Israel, August 19-24.
[17]. Rucker, D.F., Fink, J.B. and Loke, M.H., (2011). "*Environmental monitoring of leaks using time lapsed long electrode electrical resistivity",* Journal of Applied Geophysics 74(4):242-254.
[18]. Samina, S., (2007), "Effective Thermal Conductivity Measurements Relevant to Deep Borehole Nuclear Waste Disposal", M.Sc thesis, Massachusetts Institute of Technology.
[19]. Sreedeep, S, Reshma, A.C. and Singh, D.N., (2004), "*Measuring Soil Electrical Resistivity Using a Resistivity Box and a Resistivity Probe",* Geotechnical Testing Journal, Vol. 27, No. 4,Paper ID GTJ11199.
[20]. Van Rooyen, M. and. Winterkorn, H.F., (1957), "Structural *and Textural Influences on Thermal Conductivity of Soils*", Highway Research Board Proceedings 39:576-621.

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