THERMAL ANALYSIS OF ENGINEERED MULTI-BARRIER SYSTEMS FOR HAZARDOUS WASTE MANAGEMENT

A Project Report

Submitted by

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Under the guidance of

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and

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CERTIFICATE

This is to certify that the thesis entitled **“Thermal Analysis of Engineered Multi-Barrier System for Hazardous Waste Management”** submitted by ***Vinay kumar Gadi*** ***(Roll No: 213CE1043)*** in partial fulfillment of the requirements for the award of the degree of Master of Technology in Geotechnical engineering during the session 2013-2015 in the department of Civil engineering, National Institute of Technology Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the project report has not been submitted to any other University/Institute for the award of any Degree.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Soil thermal properties are of great importance in many engineering projects and other situations where heat transfer takes place in the soil. Estimation of soil thermal properties are of prodigious importance in design and laying of buried high voltage power cables, pipe lines of oil and gas, nuclear waste disposal facilities, Modification techniques of ground engaging heating and freezing and soil shrinkage studies etc.. Due to daily temperature fluctuations the solar and diffuse radiations exchange takes place at the earth’s surface. Particularly changes in the amount, phase and condition of water. This leads to variations in the thermal properties of the soil. The present research deals with the thermal properties of soils and the factors influencing them. Heat transfer depends upon thermal properties of the soil, such as specific heat, conductivity and thermal diffusivity. Thermal properties affect the soil temperature profile and soil heat flux transport and distribution. With this in view, efforts were made to develop an apparent soil method for long-term scenarios that can be applied to thermal modeling for various soils.

CHAPTER 1

INTRODUCTION

1.1 General

The world population reaches to 9 billion by next thirty years; people will consume more energy than the whole used in all previous history. Under existing patterns of energy use, the results prove catastrophic. The ensuing pollution will damage the health of millions of citizens, mainly in the developing world. Far worse, the increasing concentration of greenhouse gases will take past a point of no come back as difficulty toward climate catastrophe (World nuclear association).

The nuclear renaissance represents a convergence of developments:

- Enduring advancement in reactor technology
- Unparalleled levels of efficiency and capacity consumption in key countries
- A healthy growing record of equipped safety, supported by a persistent global nuclear safety culture
- Growth in executing the scientifically sound concept of waste disposal using deep geological repositories
- Expansive growth planning for nuclear power in major nations in both the developed and developing worlds (World nuclear association).

Wind, solar and biomass will positively play roles in future energy economy, but the energy sources cannot develop sufficient enough to transmit cheap and reliable power at the scale the global economy requires. While it may be theoretically probable to stabilize the climate without nuclear power, in the real world there is no convincing path to climate stabilization that does not include a considerable role for nuclear power.

A fair assessment shows no reasonable obstacle to a global expansion of nuclear power. As categorized by IAEA there are mainly three types of solid nuclear wastes classified in terms of its radioactivity. Those are i) Low level waste ii) Intermediate and iii) High-level wastes. Low-level waste (LLW) consists of daily refuse like paper, gloves, plastic containers, disposable overalls and overshoes with low radioactivity. LLW is packed together into drums, stored and disposed into repositories. Intermediate-level waste (ILW) mainly consists of radioactive resin and chemical sludge, spent filter cartridges etc. composed from waste treatment process and maintenance work. ILW will be hardened by mixing it with sand/cement and then poured into concrete drums. The ILW will be transported for disposal after temporary storage at the nuclear power station. HLW consists near to 95% of hazardous waste. They are rich in fission products with transuranic elements. This waste required to be shielded as it is highly hot and radioactive. They are usually disposed in deep geological repositories.

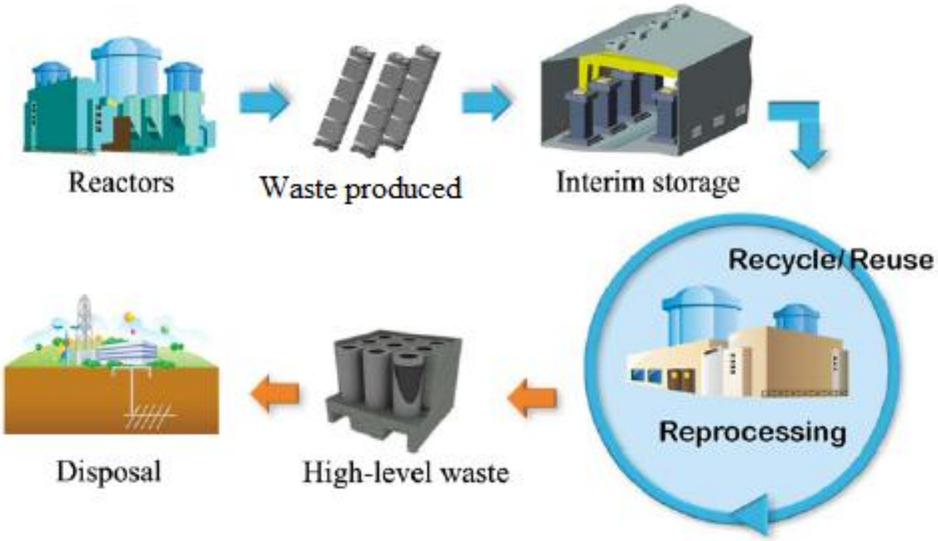


Fig. 1.1 Waste disposal procedure (modified form Kim et al. 2011)

As shown in fig 1.1 the waste which can be recycled will be separated from the waste. The remaining high level waste will be disposed deep inside the ground away from living geo environment.

1.2 Scope and Objective

The purpose of this study is determination of thermal properties of geomaterials i.e. buffer materials (sand bentonite mixtures). The main objectives are

- Developing apparent soil method for long-term scenarios that can be applied to thermal modeling for various soils.
- Determination of thermal conductivity at room temperature with the laboratory experimental setup and KD2 Pro.
- Determination of thermal conductivity at higher temperature with the laboratory experimental setup and KD2 Pro.
- Determination of thermal diffusivity at room temperature with the laboratory experimental setup and KD2 Pro.
- Determination of thermal diffusivity at high temperature with KD2 Pro.
- Observation of influence of variation of temperature and various factors on thermal properties.

1.3 Organization of Thesis

Chapter 1: Describes the introduction, scope and objectives of the present study.

Chapter 2: Presents the review of the literature related to the thermal properties of soil, methods of determination of thermal properties and limitations. It also reviews the thermal properties associated with various temperatures. Based on the reviewed literature, the critical appraisal of the same is also reported.

Chapter 3: Discusses the theoretical back ground associated with the thermal studies of porous media and the related studies.

Chapter 4: Describes the methodologies employed to obtain physical, mineralogical and geotechnical characteristics of the geomaterials and the obtained basic results are reported in this chapter. The methodology to assess the thermal characteristics of the geomaterials is also presented in this chapter.

Chapter 5: This chapter describes the results and discussions related to thermal properties experiments and also about the obtained results.

Chapter 6: Summarizes the findings and major conclusions of this study.

CHAPTER 2

LITERATURE REVIEW

2.1 General

This chapter describes available literature regarding thermal conductivity and thermal diffusivity, in view of geomaterials. This chapter also presented brief review of studies which highlighted the influence of parameters such as the moisture content, dry density etc. Further both experimental and analytical methodologies developed by the previous researchers to assess the long-term performance of geomaterials in terms of their thermal characteristics, is also presented in this chapter. In order to understand the long term behavior of buffer materials, the knowledge of thermal behavior and heat migration mechanism through them, is essential.

In view of this the reviewed literature is purposefully divided into the two categories and named as thermal conductivity studies, thermal diffusivity studies. For sake brevity the essence of these studies are presented briefly in the following sections.

2.2 Thermal conductivity studies

Radhakrishna et al. (1980) studied relation of moisture content and thermal resistivity of the soil. Due to the added moisture in the soil, a path for the flow of heat that bridges the air gaps between the soil particles provide a thin film around the soil particles or wedges at the contacts. By increasing the effective contact areas between particles, these films or wedges greatly reduce the thermal resistivity of the soil. As the moisture content increases further, the effective contact area no longer increases with increasing moisture content. A considerable decrease in thermal resistivity is not obvious when additional moisture is added to fill the pore space. The moisture content at which the bridge mechanism breaks down, resulting in an inconsistent increase in the thermal resistivity with small reduction in moisture content, which was termed as the critical moisture.

Salomone et al. (1982) indicated that the critical moisture content of fine-grained soils can be defined by the plastic limit for such soils as marine sediments have low natural dry densities. Ranges were given for the critical moisture content along with plastic limit. By the studies of various compactive efforts a typical compactive effort value was given where the optimum moisture content, plastic limit and critical moisture content are equal.

Salomone and Kovacs (1984) studied the thermal resistivity of various soils. Appraisal was given for Salomone et al. (1979), Salomone et al. (1982) and Salomone and Kovacs (1983) by comparing those with results obtained. The thermal resistivity influence of a soil was shown primarily by Soil composition, soil density, and soil moisture content. The critical moisture content was typically observed which is at the knee of the thermal resistivity versus moisture content curve. Salomone et al. (1979) presented the variation of thermal resistivity with respect to moisture content for various types of soils. It can be observed that thermal resistivity decreases as moisture content increases. Salomone et al. (1984) observed the variation of thermal conductivity with respect to both water content and dry density in same comportment.

Salomone and Kovacs (1984), a line was given as line of optimus for the critical moisture content with respect to dry density. Line of optimus gives a relation in between critical moisture content and dry density. Because for low-density soils (i.e., less than 1.6 Mg/m^3), as plastic limit of the soil is only slightly above the optimum moisture content, Salomon and Kovacs (1984) concluded that plastic limit may be used to determine the critical moisture content of soils at low dry densities for fine-grained soils from the given range by Salomone (1982).

Singh and David (2000) developed a laboratory probe based upon the principle of transient method to measure thermal resistivity of different soils for a state of compaction. The types of soil tested were clay (black cotton soil), fly ash, silty-sand, fine-sand, and coarse-sand. Black cotton soil, fly ash and the fine-sand have also been mixed (by their weight %). Total five mixes were prepared. Equations were proposed for the results obtained and the efficiency was well given with the experimental results. Probe is smaller in diameter and size. Experiments were done till the range of coarse sands only. With this probe further coarser material experiments were not conducted.

Arnepalli and Singh (2004a) proposed a generalized procedure for measuring the thermal resistivity of soils. By employing transient heat technique a probe was developed for measuring the thermal resistivity of the soil. Generalized equation was proposed and validated with experimental values. The thermal resistivity of sand and gravel, obtained from this probe, match very well with the results reported in the literature for sand, gravel and the crushed rocks.

Arnepalli and Singh (2004b) developed a field probe to find the thermal resistivity of soils. Transient heat technique was employed to the probe. The developed probe is suitable for both fine grained as well as coarse grained soils. A generalized correlation was proposed for thermal resistivity with respect to moisture content and dry density for fine grained soils and with respect to void ratio for coarse grained soils. The efficiency of the comparison with previous researchers results for the results obtained is very high.

2.3 Thermal diffusivity studies

Cass et al. (1981) measured both thermal conductivity and thermal diffusivity. An analytical expression was developed for thermal conductivity with respect to diffusion. No attempt had been done to predict the relation with density and water content. In experimental setup water bath was used. Maintaining and applying the same temperature throughout the sample whole period with water bath would be difficult and was not mentioned about it.

Roos et al. (2002) conducted experiments on blocks, using energy balance equation thermal diffusivity was done. As the experiments were on long blocks uniform distribution of temperature is big problem. The experiments need and were conducted with strong heat flux hence at low heat flux the experiments are to be done.

Krishnaiah and Singh (2003) Measured thermal diffusivity by developing experimental setup called Thermodet and observed that thermal diffusivity is practically independent of dry unit weigh. Thermal diffusivity of coarse grained soils is higher than fine grained soils, specific heat of the soil is observed to be much sensitive to the moisture content.

Krishnaiah and Singh (2006) presented soil cementitious materials thermal properties and efficiency of Thermo det. The study also indicated that the specific heat does not show any variation with dry density.

Johnson et al. (2007) obtained the relatively stable analytical results using the amplitude and logarithmic methods to calculate the apparent soil thermal diffusivity. These methods are concluded as sufficient methods for determining the apparent soil thermal diffusivity of given regions with reasonable accuracy.

Tessy and Renuka (2008) made trail by harmonic analysis to find the thermal diffusivity. The research insisted to different soil layers. The consistent analysis to find diffusivity was indicated. For insitu conditions the study obtained results. For a laboratory purpose it may not be the proper method.

Gnatowski (2009) measured thermal diffusivity using two groups of methods. First method is using amplitude, phase, arctangent and logarithmic equations. Second method is experimental. The study was given comparable results and discussed about the non-suitability of phase method. Proper correlation was not developed between thermal diffusivity and various factors like moisture content and dry density.

Danelichen (2013) determined thermal diffusivity by amplitude, logarithmic, arctangent and face methods between various depths from 0.01 to 0.15m depth. Out of all these four methods when compared with amplitude method logarithmic method gives better result at higher depths also. The studies are purely analytical and more observations are to be done.

Rubio (2014) used experimental soil device, measured thermal conductivity with decagon devices. Empirical equation was given for thermal conductivity with respect to volumetric moisture content. The study was done on a soil column (gravel) in which density is an important factor and the SH-1 sensor of KD 2 Pro. is limited depth restricted. The correlation would have been efficient by including whole specimen depth.

2.4 Summary and Critical appraisal

As the coarser fraction is increasing, the thermal conductivity increases (Salomone et al., 1979) but the stability of the barrier decreases. In transient condition rate of temperature of heated body depends on the material in which it is placed; hence depending upon the temperatures in experiments the thermo couples can be chosen. Various types of thermal probes were developed by previous researchers to measure thermal resistivity. Progress in efficiencies can be observed (Singh and David, 2000; Arnepalli and Singh, 2004a; Arnepalli and Singh, 2004b). Composite materials also need to be improved for industrial requirements (Singh and David, 2000). Regarding thermal diffusivity Krishanaiah and Singh (2003), Krishanaiah and Singh (2004) developed experimental methodology from Shannon and Wells (1947). The method is apparent, but showed that diffusivity is independent of dry density. Analytical analysis was done by some researchers (Darrell, 2007; Tessy and Renuka, 2009; Gnatowski, 2009) and results obtained were compared in between them. The proper relation and consistent variation observation was not given.

On nuclear waste buffer materials the research is to be done and is needed for modern world requirements of hazardous waste management. Generalization to the maximum accuracy in the aspect of various factors is very important for thermal properties. The thermal behavoiur at various temperatures had not been done which is an important aspect to be observed.

CHAPTER 3

THEORITICAL BACKGROUND

3.1 General

This chapter presents the theoretical background underlying the need of the hour. Attempts made by the researchers in the current area of interest have also granted a place in this section.

3.2 Terminologies

Temperature is a measure of internal motion of constituent molecules of an object. With increase in the motion, internal energy increases and so is the temperature. Heat is the thermal energy in transit. Heat is usually measured in calorie and 1 calorie is the amount of heat required to increase the temperature of 1g of water by 1^{o}C. Thermo osmosis or thermo migration is the moisture migration in response to a thermal gradient. Thermal storage capacity is equal to the area under the temperature vs. time plot after application of heat from the external source has halted.

Thermal conductivity (k) is defined as the quantity of heat that flows normally across a unit cross sectional area of a material per unit time when subjected to a unit thermal gradient along the direction normal to the surface. Evidently, the unit of thermal conductivity is cal/sec-cm-°C or it may also be expressed in terms of Watt/m-°C

$$\frac{dQ}{dt} = kA\frac{dT}{dx} \tag{3.1}$$

Where,

$\frac{dQ}{dt}$ =Rate of heat flow

k=Thermal conductivity of the material

A=Cross sectional area of the material normal to the direction of heat flow

$\frac{dT}{dx}$=Temperature gradient normal to the direction of heat flow

At a given density and moisture content, thermal conductivity is high for coarse textured soils than fine textured soils. Thermal conductivity is more for soils having high quartz content; however, it is less for soils rich in plagioclase, feldspar and kaolinite. In general, thermal conductivity of kaolinite clay will decrease with decrease in water content and increase in porosity (Reno and Winterkorn, 1967). The reciprocal of thermal conductivity is called as thermal resistivity and it is expressed in m-^{o}C/Watt (thermal ohm). Thermal needle probes find their utility for measurement of thermal resistivity (Van Rooyean and Winterkorn, 1959; Mitchell and Kao, 1977).

Dielectric constant ε gives a measure of the ability of a material to reduce the strength of the applied electric field or to behave as an insulator.

$$\varepsilon = C_s \frac{l}{A} \tag{3.2}$$

Where,

ε=Dielectic constant of the material of interest

C_s=Capacitance in Farad

l=Length of the specimen

A=Cross sectional area of the specimen

Volume-mass constitutive relationships

Gravimetric water content (w) can be defined as,

$$w = \frac{M_w}{M_s}$$

(3.3)

where,

w= Gravimetric water content

M_w=Mass of water

M_s= Mass of soil solids

Volumetric water content (θ) may be defined as,

$$\theta = \frac{V_w}{V_v + V_s} = \frac{V_w}{V} = \frac{V_w}{V_v} \times \frac{V_v}{V} = n \times S$$

(3.4)

where,

θ= Volumetric water content

V_w=Volume of water

V_v= Volume of voids

V_s= Volume solids

$V_v + V_s$=V=Total volume

$n = \frac{V_v}{V}$=Porosity

$S = \frac{V_w}{V_v}$=Degree of saturation

Degree of saturation is the ratio of volume of water to the instantaneous volume of voids. However, the instantaneous variables can be referenced back to the original volume assuming that specimen volume changes are not appreciable.

$$S = \frac{\mathrm{V_w}}{\mathrm{V_v}}$$

(3.5)

Where,

S=Degree of saturation

$\mathrm{V_w}$=Volume of water

$\mathrm{V_v}$= Volume of voids

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1 General

This chapter devotes the characterization of selected materials and the methods adopted for characterization of materials and to evaluate the thermal properties. This chapter also includes description of design and development of experimental setup and detailed methodology to obtain thermal characteristics of the selected geomaterials and their variation with moisture content.

4.2 Materials considered in this study

As described in the previous chapter the efficiency of sand bentonite mixtures which are used as buffer materials in nuclear waste disposal have studied profoundly to evaluate their efficiency as buffer material, in terms thermal characteristics, for safe disposal of nuclear waste.

To generalize the results obtained by the present study, commercial Indian standard sand of grade-III (denoted as ISS) and bentonite (denoted as BT) were considered for this study. The physical and geotechnical characteristics of these selected materials were obtained using various methodologies and details are presented below.

4.3 Physical Characteristics

4.3.1 Specific Gravity

The specific gravity (G) of the selected materials were determined with the help of a helium gas pycnometer, as depicted in Fig. 4.1 (make Quantachrome, USA), by following guide lines presented in ASTM D5550 (2006).

Fig. 4.1 Photographic view of helium gas pycnometer used for determining specific gravity of samples

The samples of the selected materials are oven dried at appropriate temperature till they attain constant weight and cooled to ambient temperature in a desiccator where relative humidity is controlled in order to prevent the adsorption of moisture from the atmosphere due to the hygroscopic phenomena. A known weight of sample is transferred to the pycnometer sample holder to measure its solid volume, with the help of Archimedes law, by purging helium gas. Prior to the measurement of solid volume, the sample is evacuated to expel the entrapped gases present in it. From the measured solid volume and weight of the sample, the solid density (i.e., specific gravity) is determined using mass-volume relationships and the obtained results along with their designation are presented in Table 4.1. In order to evaluate the thermal characteristics of sand-bentonite mixtures, the mixtures with different bentonite fraction in them such as 10, 30, 50 and 80 percent by weight is prepared based on gravimetric measurements. The specific gravity values of these sand-bentonite mixtures were obtained and the same is presented in Table 4.1.

Table 4.1 Designation and specific gravity of the samples considered in this study

Material	Designation	Specific gravity (G)*
Indian standard sand of grade III	ISS	2.70
Bentonite	BT	2.58
Sand-bentonite mixture with 10% bentonite	SB 10	2.7
Sand-bentonite mixture with 30 % bentonite	SB 30	2.67
Sand-bentonite mixture with 50% bentonite	SB 50	2.65
Sand-bentonite mixture with 80 % bentonite	SB 80	2.61

*****As per Indian standard

4.3.2. Grain Size Distribution

The grain size distribution characteristics of these selected materials were obtained by conducting both sieve and hydrometer analysis as per the guide lines presented in ASTM. For this purpose approximately 500 grams of the sample is considered and washed through 75 micron sieve under the mild jet of water, the retained material on the sieve is used for sieve analysis. Further the material passed through 75 micron sieve is collected and performed hydrometer analysis. The results from both sieve and hydrometer analysis are combined to obtain grain size distribution characteristics of the chosen materials and the results are presented in Fig. 4.2 and 4.3.

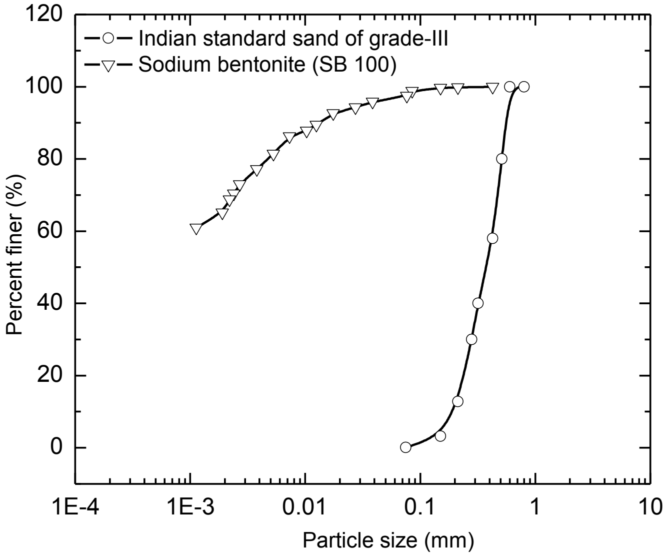


Fig. 4.2 Particle size distribution characteristics of sand and bentonite

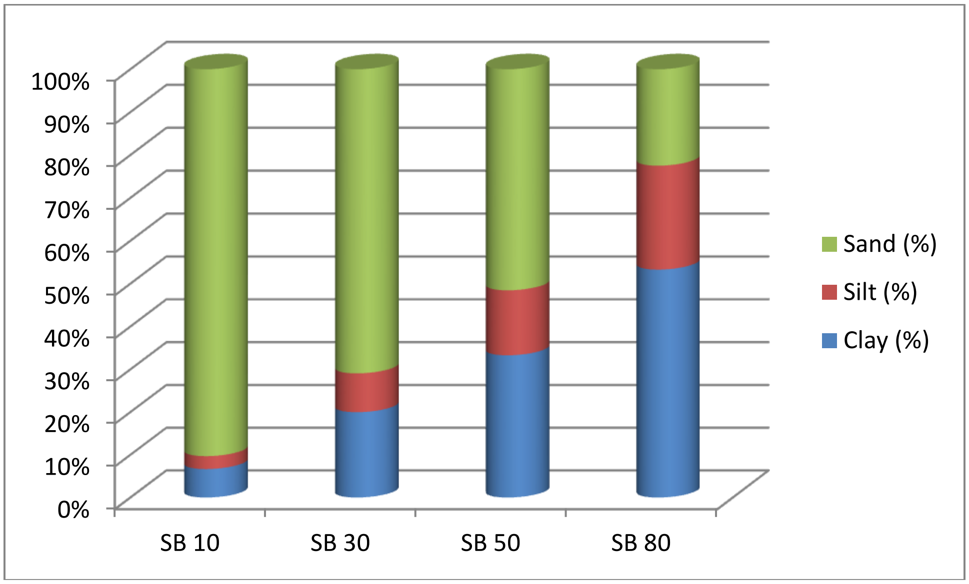


Fig. 4.3 Particle size distribution properties of fabricated materials

4.4 Geotechnical Characteristics

As discussed in the literature review chapter, the role of buffer material in high level radioactive waste disposal facilities to isolate the hazardous waste from the surrounding to minimize the interaction and possible contamination. For this purpose previous researchers have exploited the strength of sand bentonite mixtures in terms of its hydraulic barrier capabilities and efficacy as a sorbent for heavy metals and radioactive elements. Further the limitations of the bentonite in terms of its excessive swelling and shrinkage behavior, upon interaction with polar liquids, is tackled by adding the non-reactive frictional materials such as quartz based sand. Keeping in view of these facts, the present study aims to evaluate the thermal characteristics of various sand-bentonite mixtures, in terms of thermal coductivity and thermal diffusivity to assess their ability as a buffer material to contain the disposed high level waste. The influence of various factors such as dry unit weight and volumetric moisture content on their diffusion characteristics need to be elucidated. In order to achieve the above mentioned objective the present study established the compaction characteristics of various sand-bentonite mixtures using methodology described in the following.

For the compaction characterization standard proctor is used. The compaction characteristics were obtained for SB 10, SB 30, SB 50 and SB 80. The compaction results are shown in Fig. 4.4. For determination of thermal properties of geomaterials the compaction characteristics both wet side and dry side of optimum are considered and experiments are conducted.

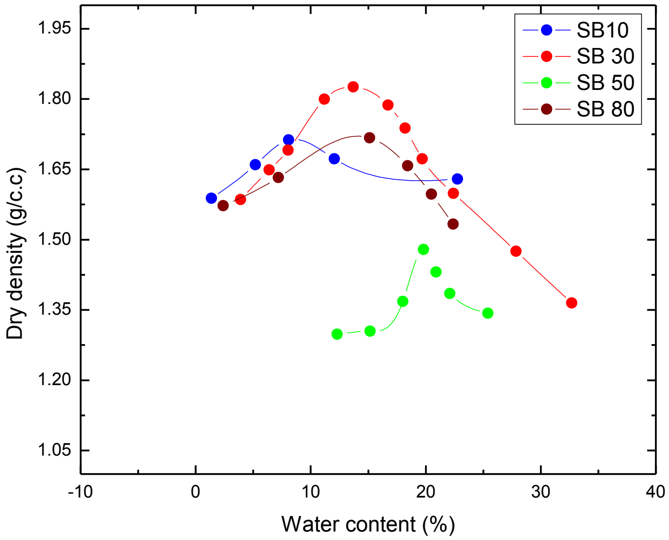


Fig.4.4 Variation of dry unit weight and gravimetric moisture content of sand-bentonite mixtures

Table 4.2 compaction characteristics of various materials used in this study

Material	**$\gamma_{d\,max}$ (g/c.c)**	**OMC (%)**
SB-10	1.696	8.55
SB-30	1.830	13.7
SB-50	1.474	19.76
SB-80	1.719	15.1

4.5. Thermal properties

As discussed earlier the thermal properties play significant role in selecting the suitable buffer material for safe disposal of radioactive nuclear waste. With this in view, the previous researchers have conducted experimental and numerical studies to understand the thermal properties of soil. In these studies, several methods and newly developed experimental setups have been used to obtain the thermal characteristics. These methods are seemed to be technically sound and consistent. However the major results obtained for thermal diffusivity depends on analytical equations and research restricted to normal temperature. There is a necessity to develop and more generalize the thermal properties studies and analysis. With this in view, the objective of the present study is to develop apparatus to obtain the thermal characteristics of buffer materials.

4.5.1 Development of thermal apparatus

The thermal property determination test setup consists of thermal probe developed by Ros (2014) which employs transient heating technique, mild steel moulds, and a constant DC supply and data logger. The temperature variation is monitored in the interval of ten seconds. The T-type thermocouples are used to measure the temperature which consists of two wires made up of copper and constantan. To avoid way in of water into the sample, when the device is submerged in water, two rubber washers are provided between the top and bottom caps of the mild steel tube. A commercial device available as KD2 Pro. is also used to measure the thermal properties of soil which was developed by Decagon devices.

The major components of the thermal property apparatus can be broadly identified as DC supply unit, Data logger and a sample mould. The DC supply unit applies the constant voltage. This voltage enables to heat the probe by applying current. The filler material Mgo which is having very low resistance uniformly dissipates the heat generated. The rate of temperature of the heated body depends on thermal coefficient of the material in which it is inserted. The whole experimental setup is shown below from Fig. 4.5 to Fig. 4.7.

Fig. 4.5 Photographic view of KD 2 Pro. (Decagon devices)

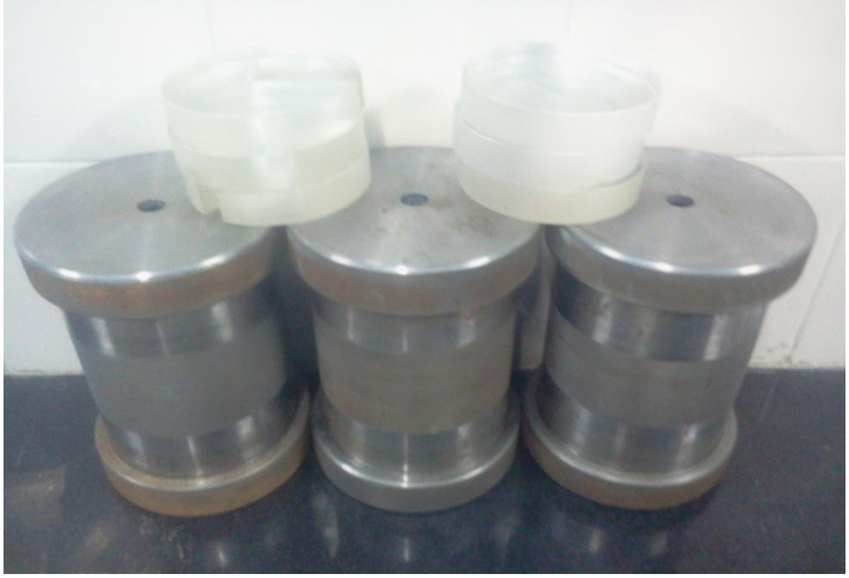


Fig. 4.6 Photographic view of Mild steel moulds

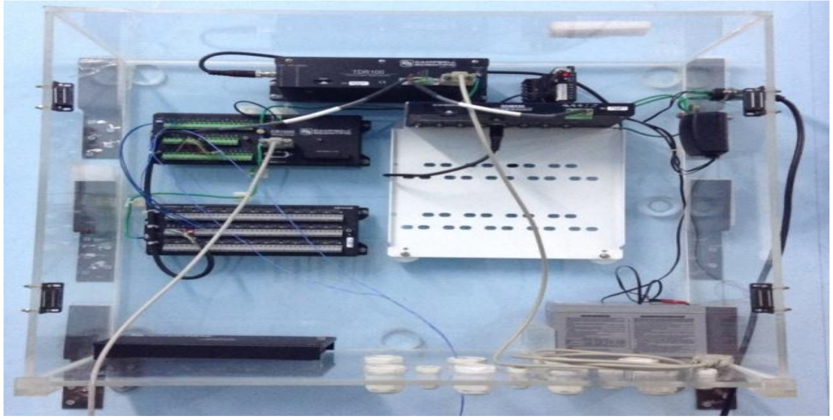


Fig. 4.7 Photographic view of Data logger (Read out unit)

4.5.2 Calibration of thermal probe

The calibration of thermal probes was done using glycerol of known thermal conductivity value. The mould was filled with glycerol and the probe was inserted into the glycerol. The calibration was done by applying different voltages like 15V, 20V, 25V and 30V. For each of these voltages, the variation of temperature with time was recorded. The thermal conductivity value obtained by applying each of these voltages was found out and compared with the known thermal conductivity value of glycerol. The thermal conductivity value of glycerol is 0.287 W/mK. From the calibration, the thermal conductivity value of glycerol at 15 V was found to be the most accurate. Fig. 4.8 and Fig. 4.9 present the variation of temperature with time monitored by the two thermocouples designated by TC1 and TC2 for different applied voltages and PT portrays the Panel Temperature (reference temperature).

A regression analysis was conducted in order to determine the percentage error while calibrating. Fig. 4.10 and Fig. 4.11 show the regression analysis done when the voltage applied was 15V. Similarly, the regression was done for each of the readings taken in order to determine the percentage error while calibrating. Further, the thermal probes were validated by conducting experiments using Indian standard sand of grade III temperature variation is as shown in Fig.4.12. The thermal conductivity value of sand ranges from 0.2-0.25 W/mK. As given in Table

4.3, the thermal conductivity value obtained from experiment lies in between the range and hence validated.

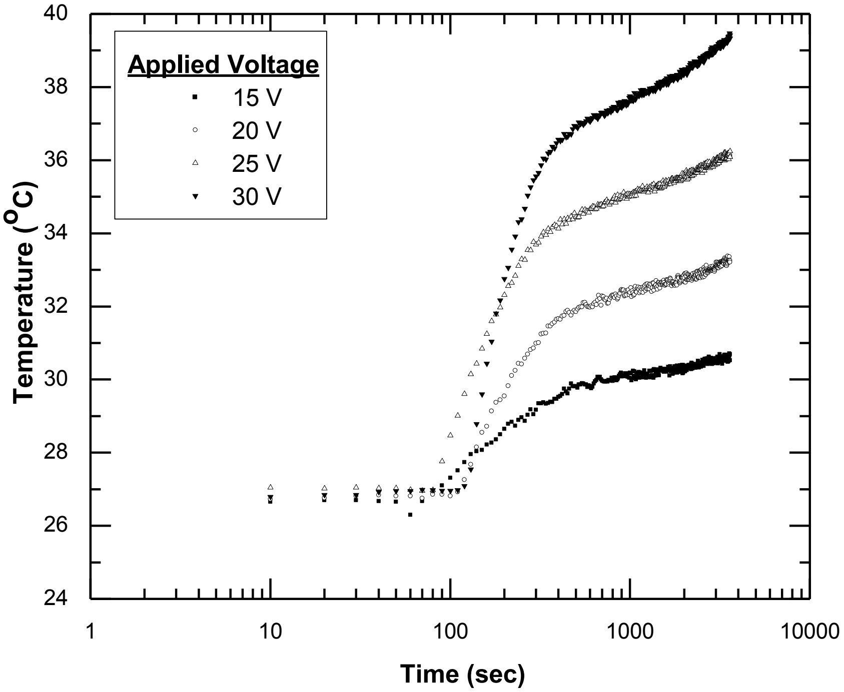


Fig. 4.8 Variation of temperature with time monitored by TC1when different voltages were applied

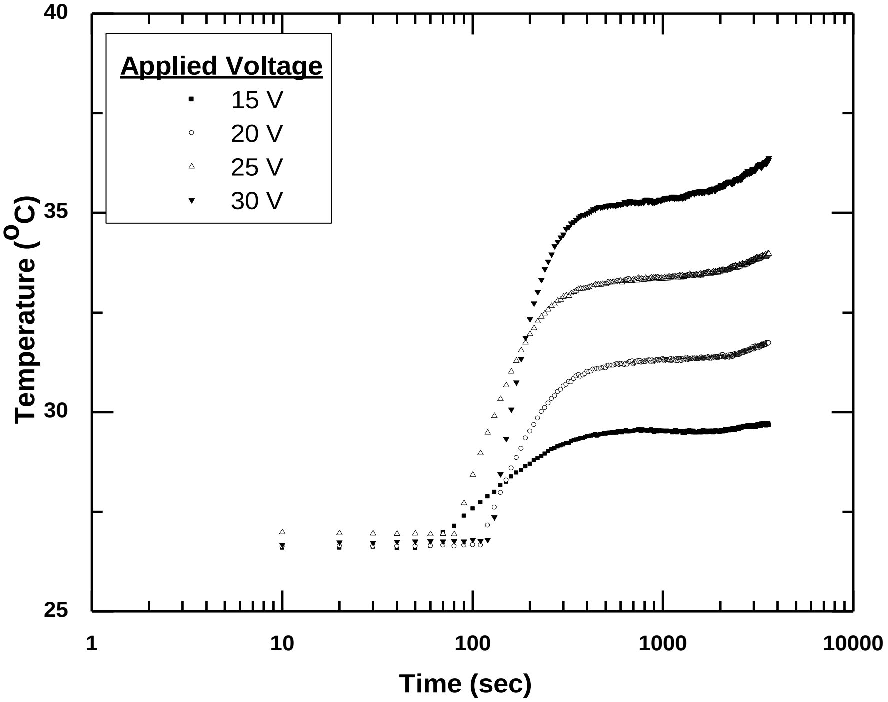


Fig. 4.9 Variation of temperature with time monitored by TC2when different voltages were applied

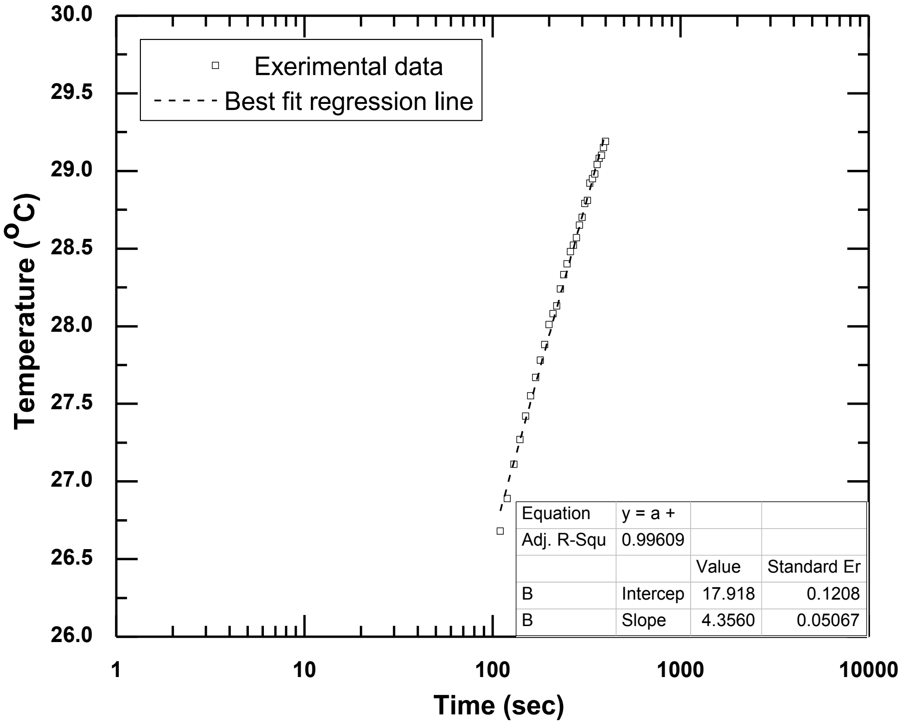


Fig. 4.10 Regression analyses of experimental data of TC1for applied flux of 15V

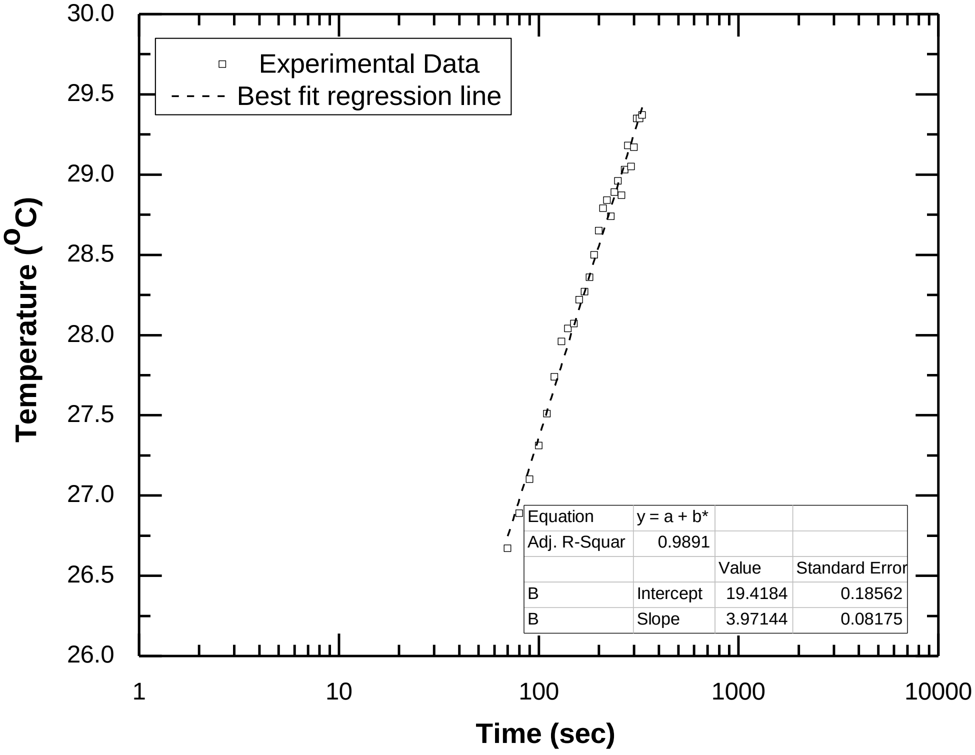


Fig. 4.11 Regression analyses of experimental data of TC2for applied flux of 15V

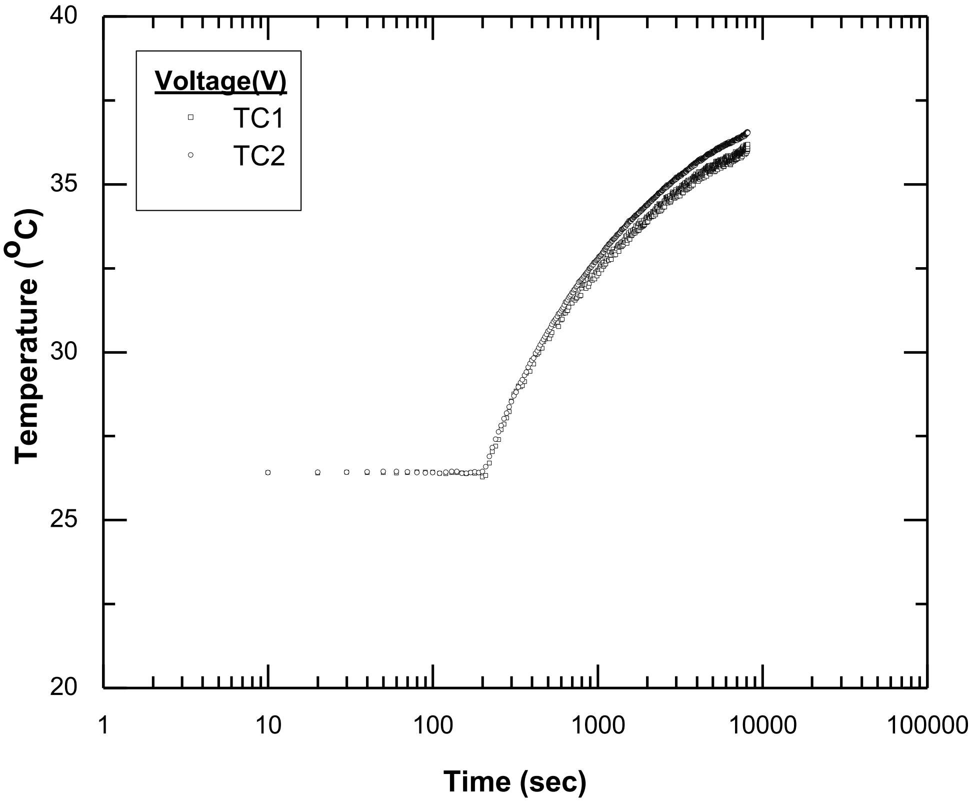


Fig. 4.12 Variation of temperature with time at 15V for sand

Table 4.3 enumerate calibration of three probes using glycerol and IS sand of grade-III. It can be readily observed that at 15V the probes predict the value of thermal conductivity more accurately. Hence, for measuring thermal conductivity of the geomaterials considered, a DC supply of 15V was applied.

Table 4.3 Calibration result using glycerol and sand

Voltage (V)	Current (I)	Thermo couple	Slope	R_T (K-cm/W)	k (W/m-K)	Percent difference	R^2 value
Glycerol							
15	0.05	1-TC1	4.356	316.92	0.316	-9.19	0.997
	0.05	1-TC2	5.122	372.67	0.268	6.78	0.970
	0.05	2-TC3	3.971	288.94	0.346	-17.21	0.989
	0.05	2-TC4	3.625	263.75	0.379	-24.43	0.995
	0.05	3-TC5	5.787	421.03	0.238	20.64	0.983
	0.05	3-TC6	6.273	456.45	0.219	30.79	0.984
20	0.06	1-TC1	12.362	562.10	0.178	61.06	0.982
	0.06	1-TC2	13.946	634.15	0.158	81.70	0.980
	0.06	2-TC3	9.605	436.74	0.229	25.14	0.986
	0.06	2-TC4	9.716	441.80	0.226	26.59	0.990
	0.06	3-TC5	13.652	620.78	0.161	77.87	0.986
	0.06	3-TC6	16.108	732.43	0.137	109.87	0.984
25	0.08	1-TC1	25.090	684.52	0.146	96.14	0.981
	0.08	1-TC2	29.737	811.30	0.123	132.46	0.969
	0.08	2-TC3	12.259	334.46	0.299	-4.17	0.992
	0.08	2-TC4	12.088	329.80	0.303	-5.50	0.990
	0.08	3-TC5	16.388	447.11	0.224	28.11	0.985
	0.08	3-TC6	18.752	511.61	0.195	46.59	0.984
30	0.10	1-TC1	22.552	410.19	0.244	17.53	0.990
	0.10	1-TC2	24.575	446.98	0.224	28.08	0.990
	0.10	2-TC3	22.226	404.26	0.247	15.83	0.987
	0.10	2-TC4	22.049	401.03	0.249	14.91	0.984
	0.10	3-TC5	25.567	465.03	0.215	33.25	0.994
	0.10	3-TC6	27.442	499.13	0.200	43.02	0.986

Indian Standard Sand-Grade III							
15	0.05	1-TC1	6.378	464.07	0.215	3.13	0.989
	0.05	1-TC2	6.231	453.341	0.221	0.74	0.987
	0.05	2-TC3	5.961	433.688	0.231	-3.62	0.927
	0.05	2-TC4	5.722	416.301	0.24	-7.49	0.994
	0.05	3-TC5	6.129	445.978	0.224	-0.89	0.972
	0.05	3-TC6	6.101	443.879	0.225	-1.36	0.975

4.5.3 Experimental methodology to obtain thermal properties

In order to evaluate the thermal characteristics of the selected material, the air dried sample is mixed with distilled water. Further the test sample is prepared by compacting the moist sample in three layers using a standard proctor into the sample mould to achieve dry density corresponding to its moisture content. Compacted samples are drilled for inserting the probe of size 10cm length and 10mm diameter. Thermal probe is inserted and sample is kept at room temperature for some time. By connecting to DC supply unit and data logger (read out unit) thermal conductivity test is conducted simultaneously. The whole setup is kept into oven at 50°C to 60 °C temperature for 6 to 8 hours with thermal probes. The samples kept in oven are taken out after stipulated time and thermal conductivity experiment is conducted again. After measuring thermal conductivity at higher temperature the whole mould is kept in water bath containing water at room temperature and the measurement with KD2 Pro. is done simultaneously. At the completion of every test the data is collected for the analysis of result.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 General

This chapter presents the results obtained using experimental methodologies described in previous chapter. Selected materials were characterized for physical, and geotechnical properties by following the procedures mentioned in the previous chapter, their thermal conductivity and diffusivity were evaluated using the newly developed experimental setup. The efficiency and suitability of selected materials, as buffer materials to dispose the radioactive wastes into it, was assessed based on thermal properties.

5.2 Thermal conductivity characteristics

According to the methodology presented in the chapter 4, the samples are prepared for required water content and with corresponding dry density. First the thermal conductivity experiments are conducted on drilled samples. The voltage set according to the accurate calibration. From the read out unit the temperature variation obtained with respect to time. Temperature with time is plotted on logarithmic scale as the unit reads the data for every ten seconds. It can be noted that temperature increases gradually and after some time it remains near to constant.

The thermal conductivity experiments for sand bentonite mixtures first conducted at room temperature. Variation of temperature with respect to time is as shown in Fig. 5.1 and the slope obtained from regression analysis is also shown in Fig. 5.2 for SB 10 at 10% water content. Fig. 5.1 shows the temperature variation at thermo couple 1 (TC 1) and thermo couple 2 (TC 2).

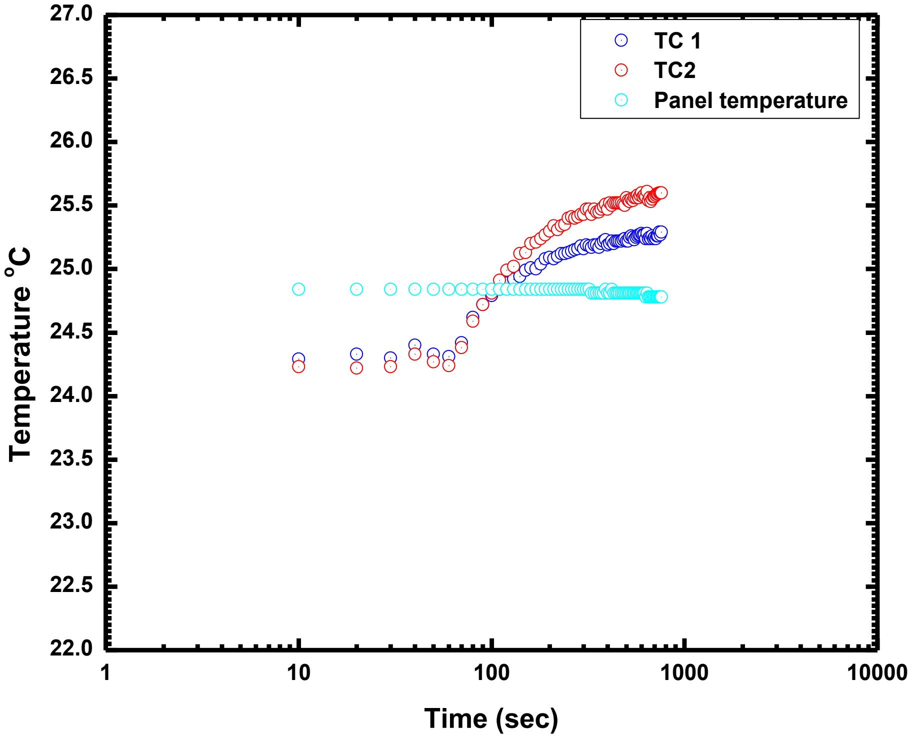
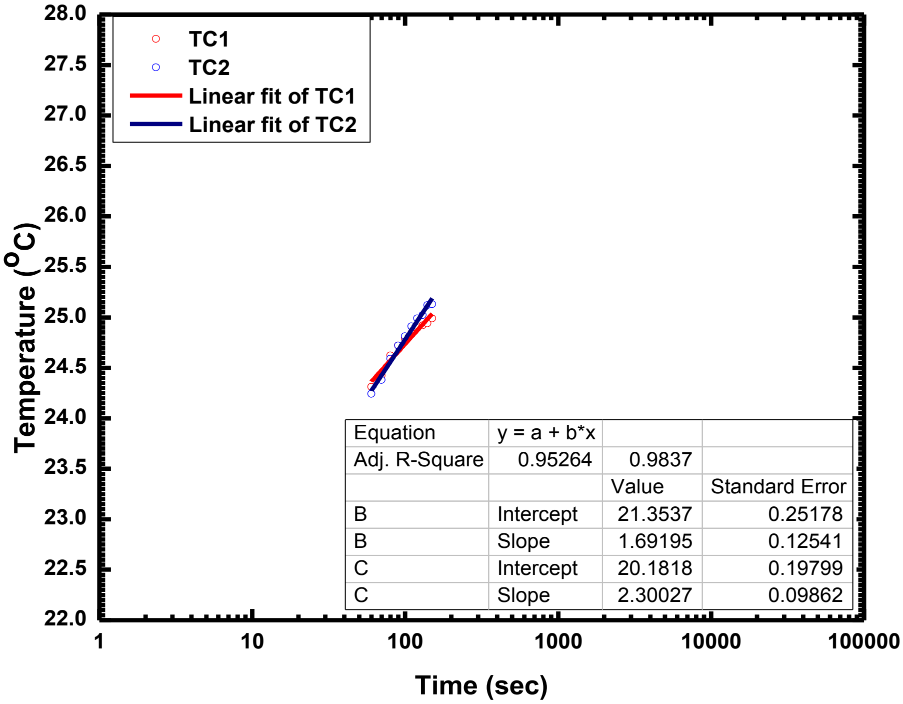


Fig. 5.1 the variation of temperature with respect to time



Equation	y = a + b*x		
Adj. R-Square	0.95264	0.9837	
		Value	Standard Error
B	Intercept	21.3537	0.25178
B	Slope	1.69195	0.12541
C	Intercept	20.1818	0.19799
C	Slope	2.30027	0.09862

Fig. 5.2 Regression analysis for the data

After taking out from oven again thermal conductivity experiment has been conducted on the sample. The results at higher temperatures are as shown in Fig. 5.3 and Fig. 5.4.Temperature variation took place from 51° C to 54.5. The regression analysis is also shown.

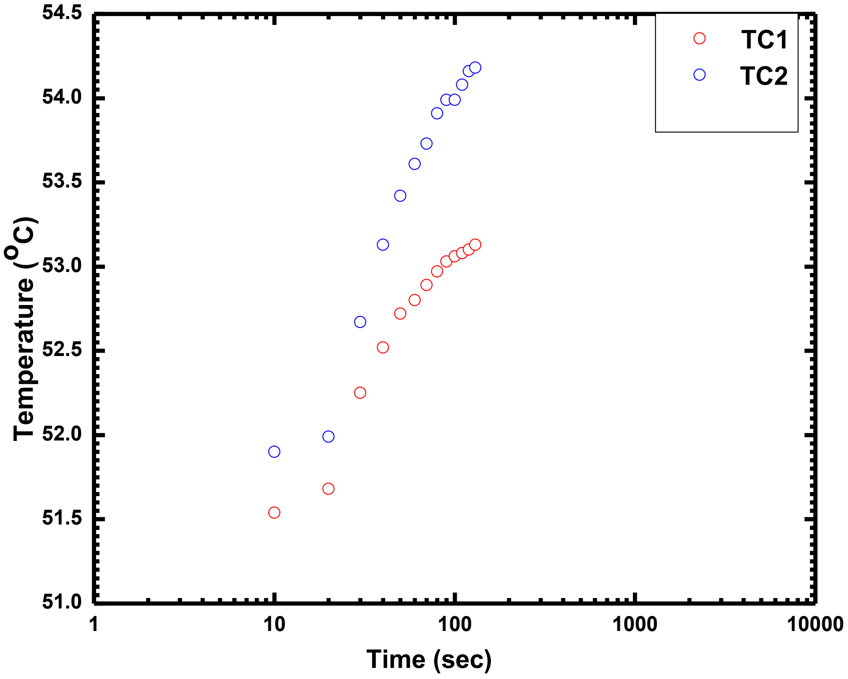
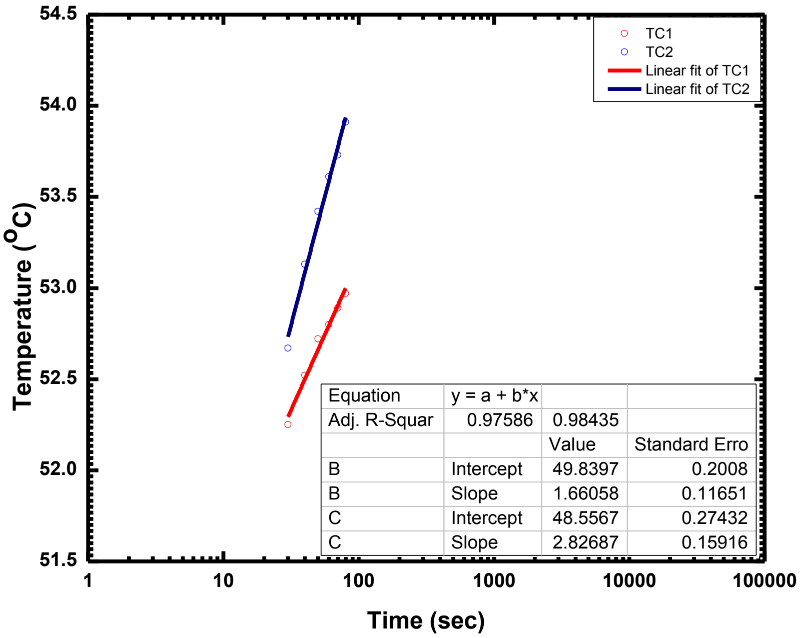


Fig. 5.3 Variation of temperature with respect to temperature



Equation	y = a + b*x		
Adj. R-Squar	0.97586	0.98435	
		Value	Standard Erro
B	Intercept	49.8397	0.2008
B	Slope	1.66058	0.11651
C	Intercept	48.5567	0.27432
C	Slope	2.82687	0.15916

Fig. 5.4 Regression analysis for data

The results include for all mixtures SB 10, SB 30, SB 50 and SB 80. It can be observed that thermal conductivity values increase with increase in water content. This can be attributed to more bonds will be bridged between molecules due to addition of water. The experiments conducted for both dry side and wet side of optimum moisture content. In few experiments the thermal conductivity at more water content at wet side of optimum is decreased little bit which employs more dispersed in structure as in literature discussed by Radha Krishna et al. (1980), Salomone and Kovacs (1982, 1984). At higher temperature the thermal conductivity values are almost same to the ordinary temperature. This may enhance the coefficient of thermal conductivity is same at higher temperature. From the observations as the bentonite content is increasing thermal conductivity increases similarly as concluded by Salomone et al. (1982). This study also recommends SB 30 as buffer material which is reasonable in stability and economy prospect.

5.3 Thermal Diffusion Characteristics

The thermal diffusion experiments were conducted by methodology discussed similar to Krishnaiah and Singh (2003) methodology. The variation of temperature with respect to time is taken from read out unit.

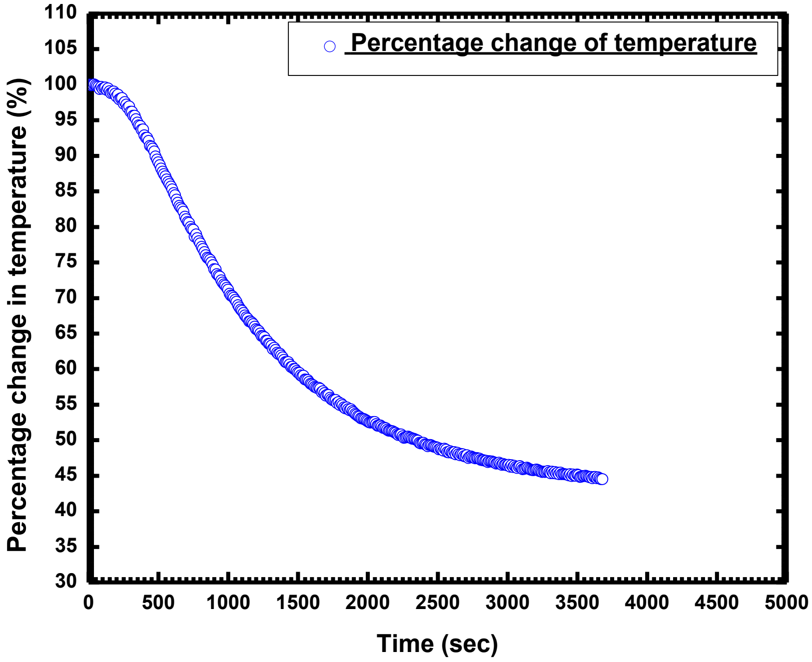


Fig 5.5 Percentage change in temperature with respect to time

The decrease in temperature in percentage is as shown in Fig. 5.5. For time factor calculation curve taken is the one used by Shannon and wells (1947), which was taken from Krishnaiah and Singh (2003) shown in fig 5.8. The thermal diffusivity results are given below.

The plot of decrease in temperature percentage with respect to time is given below for SB 10 at all gravimetric water contents as shown in Fig. 5.6. The time required to reach half of the temperature was indicated.

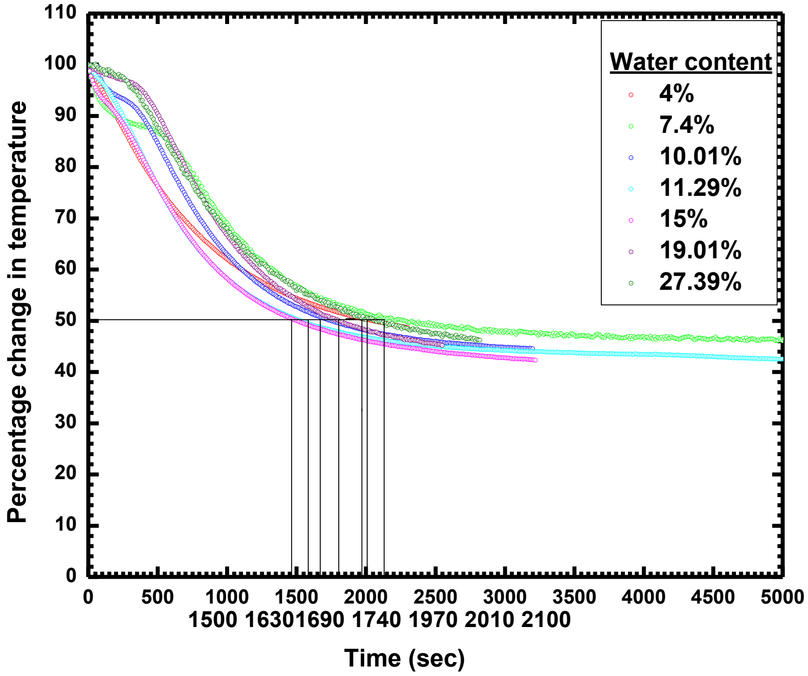


Fig 5.6 Percentage change in temperature with respect to time for SB 10

It can be observed that thermal diffusivity values increase with increase in water content which has been discussed by Krishnaiah and Singh (2006). This can be attributed to more bonds will be bridged between molecules due to addition of water. In Grain size aspect the results showing independent of percentage of finer fraction. The experiments conducted for both dry side and wet side of optimum moisture content. In few experiments the thermal diffusivity at more water content at wet side of optimum is decreased little bit which employs more dispersed in structure. At higher temperature the thermal diffusivity values are little higher than ordinary temperature. This may enhance the coefficient of thermal conductivity is little higher at high temperature.

5.4 Analysis of KD2 Pro. Results

Fig. 5.7 shows the thermal conductivity results obtained by KD2 pro. and Fig. 5.8 shows the thermal diffusion results.

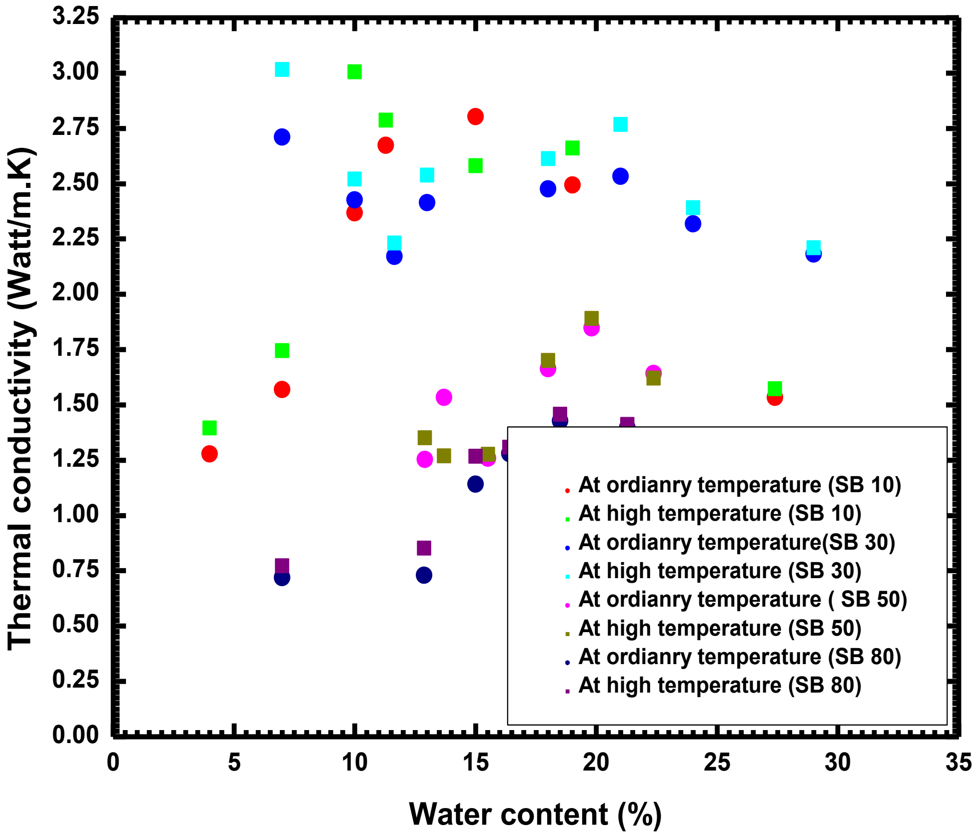


Fig. 5.7 Thermal conductivity measured with KD2 Pro.

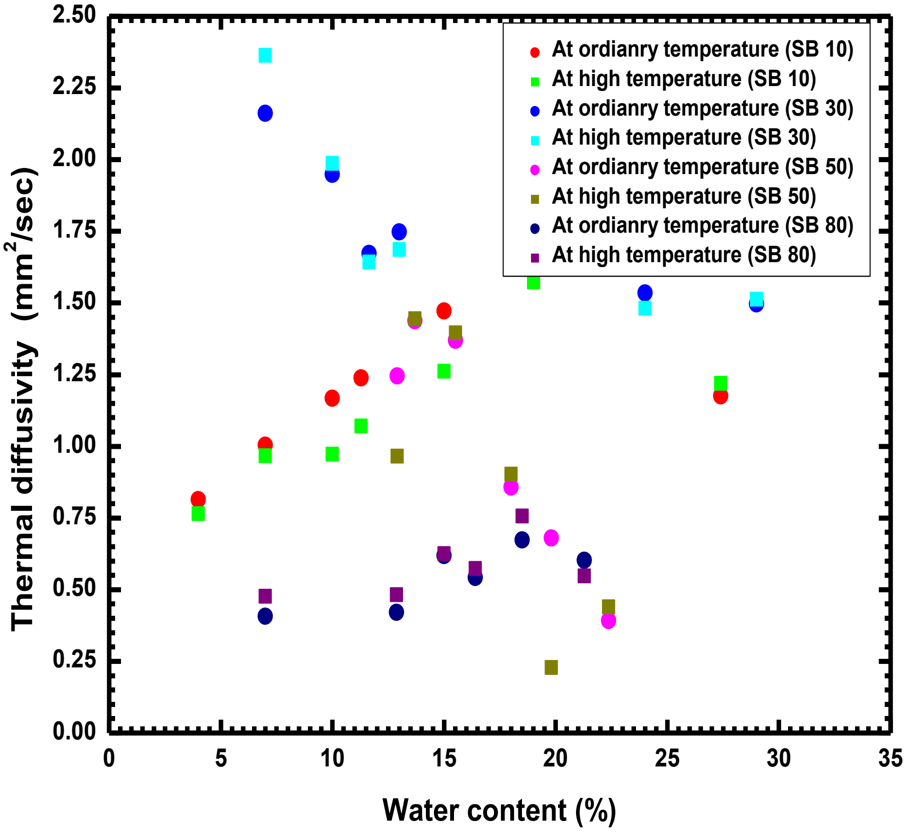


Fig. 5.8 Thermal diffusivity measured with KD2 Pro.

The KD2 Pro. results are not showing consistent variation according to grain size and water content also. The diffusivity at higher temperature is little more by KD2 pro. These results are not occurred considerable nearer to experimental and also model results.

The temperature variations Weiner (1975), Kersten (1949), Johansen (1975), DeVries (1963) models have been used for the comparison purpose; the principle and concept were proposed by previous researchers. The comparison shows reasonable consistent results. The results are more efficient with Johansen (1975) and Kersten (1949) whose deviation is less than 25%. The particular results of sand bentonite mixtures (buffer materials) bestow the proper correlation requirement of thermal properties for buffer materials which will be more beneficial to understand the behavior of geomaterials. .

CHAPTER 6

CONCLUSION

The present study investigated the thermal characteristics of various materials over a wide range of moisture contents to evaluate their performance as self-sealing materials for isolated radioactive waste. For this purpose the selected geomaterials were characterized for their physical and geotechnical characteristics prior to the evaluation of thermal characteristics. Further, a new thermal characteristic apparatus is designed and developed for precise determination of thermal properties of geomaterials over wide range of moisture contents. The thermal conductivity and diffusivity tests have been carried out at various temperatures for buffer materials such as sand bentonite mixtures and obtained the corresponding values with developed apparatus and also KD2 Pro.. Further the experimental data was compared with analytical expressions developed by previous researchers. The observations on the variation of thermal conductivity and diffusivity over a wide range of moisture content indicated an increase in values with an increase in moisture content. The observations indicated a combined influence of sample parameters such as dry unit weight, gravimetric moisture contents. The study tried to enumerate the effect of volumetric moisture content on the thermal conductivity and diffusivity. The present study satisfied the duplication for results obtained by Ros (2014) which indicates the efficiency of probe and the method developed. As from the observations in both economical as well as stability purpose SB 30 can be said as the optimum mixture for isolation of waste disposal facilities.

Future Scope of the study: According to methodology presented experiments can be conducted more number geomaterials with different sand and bentonite proportions. As the method is based on transient condition, thermal characterization can be done over a wide range of temperatures.

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