

**THERMAL CONDUCTIVITY OF FIRED CLAY OF VARIED MINERAL
COMPOSITION MADE FROM SELECTED UGANDA CLAY TYPES**

BY

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DECLARATION

I Kella Allan do hereby declare that this dissertation contains my original work and has not been submitted in whole or part to any University or academic institution for an academic award.

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APPROVAL

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DEDICATION

To my family, for their love and pride in me

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TABLE OF CONTENT

	PAGE
Declaration.....	i
Approval.....	ii
Dedication.....	iii
Acknowledgement.....	iv
List of Figures.....	vii
List of Tables.....	viii
Abstract.....	ix
 CHAPTER ONE: INTRODUCTION	
1.1 Background of the Study	1
1.2 Statement of the Problem	6
1.3 Purpose of the Study	6
1.4 Objectives of the Study.....	6
1.5 Significance of the Study	7
1.7 Scope of the Study	7
 CHAPTER TWO: REVIEW OF RELATED LITERATURE	
2.1 Introduction	9
2.2 Structure and Mineral Composition of Clays	9
2.3: Thermal Conduction by Ceramic Materials.....	8
2.5. Methods of Chemical Analysis	16
2.6: Techniques of Measurement of Thermal Conductivity of Materials	23
 CHAPTER THREE: METHODOLOGY OF STUDY	
3.1 Introduction	30
3.3 Sampling Technique	30
3.4 Materials Processing and sieving	30
3.5 Formulation of Test Specimens	32
3.6. Formation of the Green Body.....	35
3.7: Firing.....	36
3.8: Experimental Measurements.....	37
3.8.1: Chemical Characterization of Mineral Samples.....	37

3.8.2: Measurement of Thermal Conductivity	38
CHAPTER FOUR: RESULTS OF STUDY	
4.1 Introduction	39
4.2 Thermal Conductivity of specimen with varying Quartz	39
4.2 Thermal Conductivity of specimen with varying ball clay	40
4.3 Thermal Conductivity of specimen with varying feldspar	41
4.4 Thermal Conductivity of specimen with varying kaolin	42
4.5: Thermal Conductivity of specimen with varying all the minerals	43
CHAPTER FIVE: DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS	
5.1 Discussions	46
5.2 Conclusions.....	47
5.2 Recommendations.....	48
REFERENCES.....	49
APPENDIX A.....	53
APPENDIX B.....	58
APPENDIX C.....	59
APPENDIX D.....	60

LIST FIGURES

	PAGE
Figure 2.1: Molecular model of Structure of Kaolin.....	11
Figure 2.2: Microscopic Illustration of Thermal Conduction	15
Figure 2.3: Fourier's homogenous solid to determine thermal conductivity	16
Figure 2.4: Intensity output from Mo anode X-ray tube at different voltages.....	18
Figure 2.5: Wave length-dispersive spectrometer.....	19
Figure 2.6: Typical temperature rise curve (a-ideal, b- non-ideal case).....	28
Figure 3.1: Sieves on a mechanical vibrator	31
Figure 3.2: Hydraulic press machine PW-40	35
Figure 3.3: Experimental set up used for thermal conductivity measurement.....	37
Figure 4.1: Bar chart for change in mineral composition Quart.....	40
Figure 4.2: Bar chart for change in mineral composition of Ball clay	41
Figure 4.3: Bar chart for change in mineral composition of Feldspar	42
Figure 4.4: Bar chart for change in mineral composition of Kaolin	43
Figure 4.5: Bar chart for change in all the mineral compositions.....	44
Figure 4.6: Bar chart for different mineral formulations.....	45

LIST OF TABLES

	PAGE
Table 2.1: Chemical composition of Kaolin, Feldspar, Ball clay and Quartz	14
Table 2.2: Chemical composition of fired samples.....	24
Table 2.3: Properties of typical firebricks (adapted from UNEP, 2006).....	23
Table 3.1: Samples made with varying ratios of Quartz.....	32
Table 3.2: Samples made with varying ratios of Ball clay	33
Table 3.3: Samples made with varying ratios of Feldspar.....	33
Table 3.4: Samples made with varying ratios of kaolin	34
Table 3.5: Samples made with varying entire mineral ratios	34
Table 3.6: Chemical composition of Kaolin, Feldspar, Ball clay and Quartz	36
Table 4.1: Thermal conductivity of the samples made with varying ratios of Quartz.....	39
Table 4.2: Thermal conductivity of the samples made with varying ratios of Ball clay....	40
Table 4.3: Thermal conductivity of the samples made with varying ratios of Feldspar...	41
Table 4.4: Thermal conductivity of the samples made with varying ratios of Kaolin.....	42
Table 4.5: Thermal conductivity of the samples made with varying all the minerals.....	43

ABSTRACT

The use of thermal insulators is one of the most important applications in thermal energy conservation systems. This study determined the effect of varying mineral compositions on thermal conductivity. Dry powders of kaolin, ball clay, quartz and feldspar were prepared by ball milling, sieved to particle size of 45 μ m and then mixed in different proportions to make 100g. For each formulation, three of the four minerals were kept in fixed proportions by mass while varying one. Eighty clay rectangular shapes of dimensions 100mm x 50mm x 20mm were compressed at a pressure of 75MPa and then fired to a maximum temperature of 1200°C.

The first formulation had the proportion of Quartz varied while that of other minerals fixed. The second formulation had the proportion of Ball clay varied while that other three fixed. The third formulation had the proportion of feldspar varied while that other three fixed. The fourth formulation had the proportion of kaolin varied while that other three fixed. And the fifth formulation had the proportion of all the minerals varied. The Quick thermal conductivity meter was used in the measurement of thermal conductivity at room temperature of approximately 25 °C.

The study showed that thermal conductivity value increased with increasing proportion of Quartz from 3.305x10⁻¹ to 3.32x10⁻¹ Wm⁻¹K⁻¹. Thermal conductivity values also increased with decreasing proportion of ball clay from 3.225x10⁻¹ to 3.267x10⁻¹Wm⁻¹K⁻¹. The thermal conductivity value increased with increasing proportion of Feldspar from 3.313x10⁻¹ to 3.274x10⁻¹ Wm⁻¹K⁻¹. The thermal conductivity value increased with decreasing proportion of kaolin from 3.179x10⁻¹ to 3.28x10⁻¹ Wm⁻¹K⁻¹. And when all the mineral proportions was varied, The thermal conductivity value increased with decrease in proportion of kaolin and ball clay in each mixture, and ranged from 3.239x10⁻¹ to 3.288x10⁻¹ Wm⁻¹K⁻¹.

From the samples studied, formulation consisting of (Quartz-15%, Ball clay-15%, Feldspar-15%, and Kaolin-55%) was the best insulating material with thermal conductivity value of 0.3179 Wm⁻¹K⁻¹. The highest thermal conductivity values was due to high proportions of quarts, while the lowest thermal conductivity values was due to high proportions of kaolin.

The study recommended further work to be done on thermal conductivity of clays by varying pressure, particle size, firing temperature and the impact of combustible organic wastes on the thermal conductivity.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Clay is a natural earthy fine grained material, which is powdery when dry, plastic when wet and stone-like when baked (Mohammed et al., 2011). Most clay types are crystalline, with a definite repeating arrangement of atoms in them. The majority of them are made up of planes of oxygen atoms, with silicon and aluminum atoms holding the oxygen together by ionic bonding (Brady et al., 1999). Clay minerals have the ability to exchange ions. This mineral property of clays that causes ion in solution to be fixed on the clay surface or within internal sites applies to all types of ions, including organic molecules. (Hans., 1994).

Clay has been widely used as a raw material in constructions and buildings materials since 8000 BC (Houben & Guillaud, 1994). Clay is known to be used in pottery, in industrial kilns and furnaces and in producing several electronic devices. The applications of clay are highly dependent upon its structure, composition, and physical attributes (Grim.R, 1960). The knowledge of the characteristics of clay can help in its best exploitation and eventually may open-up new areas of its application. Clays are widely used in the manufacture of many traditional ceramic articles. Each ceramic product requires clays to have particular and appropriate characteristics. In many applications, clay is required not to exhibit a swelling phase.

Their loss in weight and shrinkage after drying and firing has to be low (Aydin. A, 2004). Clay bodies undergo several changes during drying and firing stages as a result of physical, chemical and mineralogical modifications. Kaolinite-illite is the most widely used clay mixture in the ceramic industry. Illite is one of the main clay phases used for the preparation of mixtures for traditional ceramics. The knowledge of the mineralogical phase composition of the raw materials used for the preparation of ceramic mixtures is of principal importance for understanding of the technological properties of ceramic products and optimizing of firing cycles in production.

Clays are generally mixed and blended to give standard compositions and optimum properties for various applications (Bailey R.T, 1974). The microstructure and properties

of clays depend on the characteristics of the parent clay and the processing conditions. Due to their inherently complex physical and chemical characteristics, clays exhibit unique properties dependent on their own natural genesis (Gomes, 1989). Many ceramic products are manufactured from mixtures of raw materials composed essentially of clays materials such as quartz, feldspar and carbonates. In the fabrication process, the raw materials are mixed in variable proportions taking into account the influence of each component on the properties of the final products (Sousa, S.J.G. and Holanda, J.N.F., 2005). The components that play fundamental roles for optimum processing and hence performance of the final products are ball clay for plasticity, feldspar for fluxing and silica as filler material (Celik, H., 2010).

The Clay minerals according to the Geological Survey of Uganda Chamber of Mines and Petroleum (UCMP) are widely spread in many parts of Uganda (<http://www.uganda-mining.go.ug/webudis>). The Feldspar deposit in Mutaka is estimated to be about 2.8 billion tons. There are also large deposits of ball clay in Mukono and the swampy areas around the shores of Lake Vitoria, flint from Mutaka, and kaolin from Namasera, Mutundwe and Mutaka, feldspar from Lunya, Karamoja and Mutaka (Kirabira, 2005). The clays from these locations have been used to produce rather poor quality bricks, tiles and pottery by local methods for several years. Scattered clay pits and brick kilns along the road sides show the low-technology exploitation of the Uganda clay occurrences.

The conservation of energy is an essential step all need to take towards overcoming the mounting problems of the worldwide energy crisis and environmental degradation. In particular, developing countries are interested to increase their awareness on the inefficient power generation and energy usage. However, usually only limited information sources on the rational energy conservation are available. The know-how on modern energy saving and conservation technologies should, therefore, be disseminated to government and industrial managers, as well as to engineers and operators at the plant level. It is particularly important that they acquire practical knowledge of the currently available energy conservation technologies and techniques.

In December 1983, United Nation Industrial Development Organization (UNIDO) organized a Regional Meeting on Energy Consumption as well as an Expert Group Meeting

on Energy Conservation in small- and medium-scale industries for Asian countries. During these meetings, it was brought out that, for some energy intensive industries; savings up to 10% could be achieved through basic housekeeping activities, such as auditing and energy management.

The ceramic industry consumes much energy. The industry is also noted for great percentage of the energy cost in the total production cost. In the ceramic industry, appreciable amounts of energy could be saved or conserved by preventing of leakage in the kilns and controlling of combustion, modifying the equipment to recover heat from the kiln in the process of ceramic-firing. The thermal properties of building materials are of importance for the designer of energy efficient buildings. This includes light insulating materials which can be used to reduce the heat losses through the building envelope, but also materials with high thermal inertia that can store heat and delay the conduction of heat through structural elements. The most common example of the latter type of material is concrete that is widely used in the building sector to make for example slabs on the ground, walls (both precast, cast on site and in the form of concrete building blocks), floors (both precast and cast on site), and roof tiles. In all these applications the thermal properties of the concrete will influence the performance of the building. For example the efficiency of cast-in flooring systems will depend on the thermal properties of concrete, concrete roof tiles will to some extent buffer day-time solar radiation and night-time heat losses, and all concrete structures inside the insulation of the building envelope will decrease indoor temperature variations.

Another scenario where significant savings can be made with thermally heavy buildings in cold climates is if the energy price will follow the cost of energy production and thus increase significantly during cold spells. A thermally heavy building can then save heating costs by not needing heat during cold-spells a similar situation exists for cooling needs in warm climates. However, a prerequisite for this is that the indoor temperature is allowed to change significantly as no savings are possible with a constant indoor temperature.

It is necessary to use thermal insulating materials around thermal energy storage systems to minimize heat losses from the systems (Turner W.C & Maloy J.F.,1988). There are varieties of insulating materials which come in various forms like loose fill, rigid boards,

pipe and foam. The thermal insulation is provided by embedding insulation materials at least on the roof areas and the vertical walls of the storage systems (Novo A.V, Bayon J.R., 2010). Poor thermal insulation of the heat storage systems leads to high heat losses. Proper selection of the insulating material to be used is based on the thermal properties which include the;- specific heat capacity, thermal diffusivity and thermal conductivity. Good ceramic insulators (Refractories) have enormous heat capacities and can withstand high temperatures, as well as other strains exerted on them such as abrasion, impact, thermal shock, chemical attack and high level loads at elevated temperatures. They are commonly applied in lining of furnaces. Refractory are classified based on composition, (such as alumina content) and physical or industrial characteristics like thermal stability. They are also classified into “Basic and Acidic” types with a third and intermediate group. Basic refractory include magnesia-chromates or chromate-magnesia, forsterite and dolomite. Acid refractory include the alumino-silicates e.g. the clays, kyanites, silimanite, andeladsite, anpolymphis, and Alumina refractory. The third category, which usually have relatively limited application than the major categories, include Zircon and Zirconia, graphite, silicon-carbide and carbon.

To improve the thermal performance of insulation facilities and to save on the loss of energy used for cooling and heating due to high temperature differences, the roofs and walls of the facilities must be well insulated by a suitable thermal insulation material. The thermal insulation material decreases the need for using cooling and heating equipment. Thermal insulation can be increased with specially engineered methods or processes as well as with the use of suitable object shapes and materials. The thermal insulation provides a region in which thermal conduction and radiation are reduced. The insulation capability of a material is measured in terms of thermal conductivity. Low thermal conductivity is equivalent to high insulating capability. In thermal engineering, other important properties of insulating materials such as density and specific heat capacity become important. Low thermal conductivity materials reduce heat fluxes.

High temperature ceramic coatings are often used on parts that are exposed to extremely high temperatures. Ceramic coating can be applied over chrome, aluminum, carbon steel, stainless steel or cast iron. It is ideal for parts exposed to extreme temperatures (2,000°F)

such as exhaust pipes, headers, manifolds, turbo housings, intakes and brackets. Ceramic coatings are commonly applied to exhaust manifolds, motorbike exhaust systems, exhaust headers, turbocharger housings and exhaust downpipes, heat shields and intake pipes and tailpipes. High temperature coatings are designed to prevent corrosion of exhaust systems and engine components. The high temperature coating product can withstand temperatures in excess of 1200 degrees and some coatings can withstand temperatures higher than 1600 degrees. The high temperature coating process can also increase the durability and provide thermal insulation to the exhaust system

Insulators are required to satisfy primarily some or all of the following characteristics depending upon the service condition; High refractoriness, Resistance to chemical reaction with any substance in contact during service, Ability to withstand the load of the material at the operating temperature, Resistance to thermal shock caused by alternate heating and cooling, Porosity (volume and nature) and Low volume changes at the service temperature (both permanent and reversible)

The resistance to thermal flow through solid materials is a desirable property which is shown by their low thermal conductivity, (Straube, 2010). Though thermal conductivity and diffusivity of kaolin and ball clay with varying particle sizes was done by Bwayo in 2014 and refractoriness of kaolin and ball clay in the production of refractory bricks by Kirabira in 2005, little attention has been put on the effect of varying mineral composition of clay minerals on the thermal conductivity. The thermal conductivity of fired clay materials composed of various mineral ratios had to be investigated to assess their viability for thermal insulation application. This endeavor was focused on the production of efficient thermal insulating material from local available clay deposit in Uganda.

1.2 Statement of the Problem

In Uganda, there are many local materials available for consideration as thermal insulators. Most of these local materials are available naturally. Clay is one of the common refractory materials used in furnaces and kilns for insulation in form of fire bricks. Despite the abundance of these raw clay materials in Uganda, the inner linings of these insulated facilities are still made from imported materials. This is because of inadequate research focused on viability of using these clay materials to build them. Most thermal insulation materials are imported from other countries like China, India and United Arab Emirates. The taxation and shipping costs is so high making them very expensive to both private and national economy. There was therefore, need to investigate the thermal conductivity of the locally available minerals to check their viability for commercial purposes.

1.3 Purpose of the Study

The study was to determine the thermal conductivity of the fired clay made from varied mixtures of selected Uganda clay minerals.

1.4 Objectives of the Study

To achieve the aim of the study, the following specific objectives were set:

- i. Determine the chemical compositions in the different clay mixtures of the four mineral types.
- ii. Determine the thermal conductivity of the different mineral composition.
- iii. Compare the thermal conductivity values for the different mineral formulations and identify the compositions that have highest and lowest thermal conductivities.

1.5 Significance of the Study

The study was to determine the thermal conductivity of the fired clay made from varied mixtures of selected Uganda clay minerals. The study provided base value for thermal conductivity for the different mixtures of Uganda clay minerals which was in the range of $0.3179 \text{ Wm}^{-1}\text{K}^{-1}$ - $0.3320 \text{ Wm}^{-1}\text{K}^{-1}$. The results of this study will assist the ceramic industry in Uganda to select suitable clay minerals ratios when manufacturing insulation materials. For good insulators would be (Quartz-55%, Ball clay-15%, Feldspar-15%, and Kaolin-15%)

The cost of cooling and heating to maintain acceptable temperatures in homes, offices and in industries due to high electricity will be reduced when insulation materials are produced using the data already obtained from this study.

Since the results obtained was in consistence with international standards for low density insulation materials, it means that the materials currently imported for the production of insulation materials used in heat storage facilities like inner linings of furnaces and kilns can be made locally within the country. Hence the costs incurred in the importation will be minimised.

1.7 Scope of the Study

The study focused on the four major minerals that is Ball Clay from Ntawo in Mukono, feldspar, kaolin and quartz from Mutaka deposits in Bushenyi district. The choice of the deposits was based on the study by Olupot and Kirabira who reported on Ntawo clay as having 67.2% silica used as a plasticizer and binder material (Olupot, 2010) and Mutaka kaolin having 36% of alumina used as a refractory material (Kirabira, 2005; Miguel, 2013). The study was made on specific particle size of $45\mu\text{m}$ which was determined after performing an exploratory experiment while varying the type and quantities of minerals within the clays. Eighty pieces of slab (100g each) of dimension (100mm x 50mm x 20mm) was compressed to a pressure of 75MPa, fired to a peak

temperature of 1200°C and their thermal conductivities measured using Quick thermal conductivity meter QTM-500.

CHAPTER TWO: REVIEW OF RELATED LITERATURES

2.1 Introduction

The review of related literatures focused on the structure and mineral composition of clay, thermal conductivity by ceramic materials, factors that affect thermal conductivity and thermal conductivity measurements.

2.2 Structure and Mineral Composition of Clays

The advancement of technology especially X-ray diffraction made it possible for scientists to understand the molecular nature of clay structure and component of clay minerals. (Baily,S.W.,1980). Clay is classified as residual, found in the places of origin and as transported (sedimentary) clay, if removed from the place of origin by an agent and deposited to a new position. Residual clay is majorly formed by surface weathering of rocks which gives rise to clay by chemical decomposition of rocks, solution of rocks and by disintegration and solution of shale. Clay minerals are hydrous aluminum phyllosilicates, sometimes with variable amounts of iron, magnesium, alkaline and other cations found on or near some planetary surfaces. (Moore,D & R.C. Reynolds, 1997). Clay minerals is classified as 1:1 or 2:1, whose origin is fundamentally built of tetrahedral silicates sheets and octahedral hydroxide sheets (Bergaya,F&Lagalya,G 2006). The 1:1 clay could consist of one tetrahedral sheet and one octahedral sheet, and examples would be kaolinite and serpentine. The 2:1 clay consists of an octahedral sheet and sandwiched between two tetrahedral sheets, and examples are talc, vermiculite and montmorillonite. The conductivity behavior of clays is much influenced by their chemical composition. The most important components are the Al_2O_3 and SiO_2 , since they have a decisive influence on the refractoriness and strength of the final product.

The major clay minerals of interest in this study are feldspar, ball clay, kaolin and quarts. Each have been discussed independently as below;-

Feldspars are a group of rock-forming tectosilicate minerals that make up as much as 60% of the Earth's crust. Feldspars crystallize from magma as veins in both intrusive

and extrusive igneous rocks and are also present in many types of metamorphic rock. The general formula for the feldspars is $XAl(Al,Si)Si_2O_8$, where X is potassium, sodium, calcium, or barium. The Al occupies some of the tetrahedra. All the X ions are big, much larger than iron or magnesium, which are too small to occupy the voids in the structure fully.

The potassium feldspars ($KAlSi_3O_8$) differ in the ordering of Al-Si tetrahedra. At high temperatures the tetrahedra are randomly mixed (although Al-O-Al links never occur) and the lattices are therefore of high symmetry. Potassium feldspar ($KAlSi_3O_8$) and the sodium feldspar *albite* ($NaAlSi_3O_8$) are completely compatible at high temperatures. However, at low temperatures the difference in ionic radius begins to tell and the feldspar separates into discrete streaks and patches of K and Na feldspar. Feldspar is majorly used as a flux, however because of some little amount of alumina nearly 16% (A.O. Oladiji, & J.O. Borode., 2010) makes it to have slightly low thermal conductivity.

Ball clay is a fine-grained highly plastic, mainly kaolinitic, Sedimentary clay, the higher grades of which fire to a white or near white color in an oxidizing atmosphere. They consist of varying proportions of kaolinite, mica and quartz, with small amounts of organic matter and other minerals, and are commercially values because they increase the workability and strength of various ceramic bodies and have white or near white firing characteristics. The fired properties of ball clays vary in accordance with their chemical and mineralogical composition. It is also necessary to know how the various elements present are distributed as minerals, where the SiO_2 , Al_2O_3 , Fe_2O_3 and alkalis are known, the amount of each of these in combination as kaolinite, hydro muscovite and quartz must be established. Ball clay with a high iron and titanium content will fire to a darker color than one with a lower content of the two, but where some of the iron occurs as a substitution for aluminum in the lattice it has less effect on the fired color than when free iron is present as limonite or siderite. Given proper firing conditions, the carbonaceous matter which is the cause of this dark color in the raw clay should be all oxidized to carbon dioxide and eliminated from the body. Ball

clay consist of 18.2% alumina (Kirabira, 2005). This makes it to have a lower thermal conductivity value compared to feldspar.

Kaolin is a clay mineral, part of the group of industrial minerals, with the chemical composition $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$. It is a layered silicate mineral, with one tetrahedral sheet linked through oxygen atoms to one octahedral sheet of alumina octahedra. Kaolin has a low shrink-swell capacity and a low cation-exchange capacity (1–15 meq/100 g). It is a soft, earthy, usually white mineral (di-octahedral phyllosilicate clay), in many parts of the world, it is colored pink-orange-red by iron oxide, giving it a distinct rust hue. Lighter concentrations yield white, yellow or light orange colors.

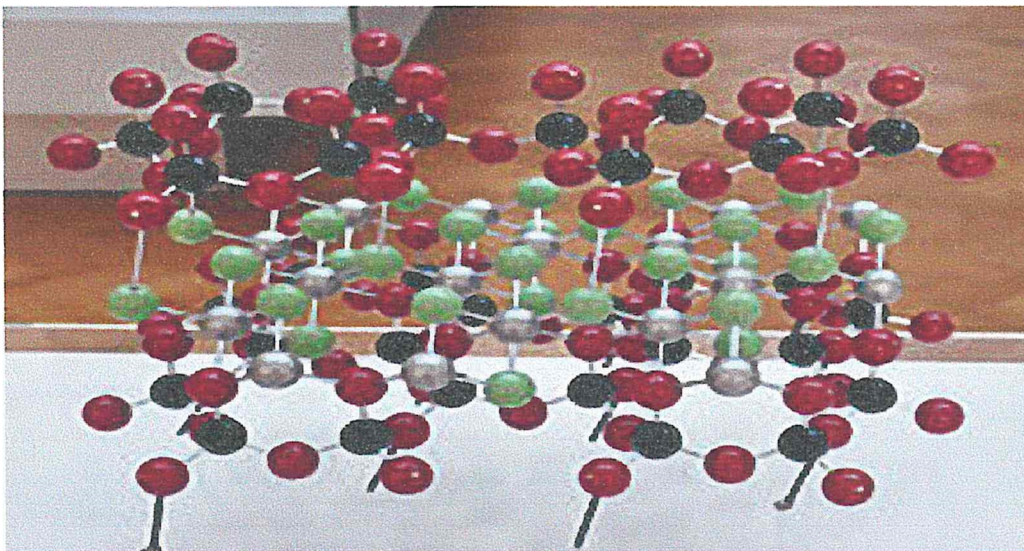


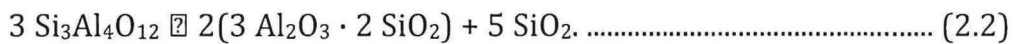
Figure 2.1: Molecular model of Kaolin structure (from Dale. L 2001)

Kaolin clays undergo a series of phase transformations upon thermal treatment in air at atmospheric pressure. Below 100 °C (212 °F), exposure to dry air will slowly remove liquid water from the kaolin. The end-state for this transformation is referred to as "leather dry". Between 100 °C and about 550 °C (1,022 °F), any remaining liquid water is expelled from kaolin. The end state for this transformation is referred to as "bone dry". Through this state, the expulsion of water is reversible: if the kaolin is exposed to liquid water, it will be reabsorbed and disintegrate into its fine particulate form. Subsequent transformations are *not* reversible, and represent permanent chemical changes. Endothermic dehydration of kaolin begins at 550–600 °C producing

disordered metakaolin, but continuous hydroxyl loss is observed up to 900 °C (1,650 °F). Although historically there was much disagreement concerning the nature of the metakaolin phase, extensive research has led to a general consensus that metakaolin is not a simple mixture of amorphous silica (SiO₂) and alumina (Al₂O₃), but rather a complex amorphous structure that retains some longer-range order (but not strictly crystalline) due to stacking of its hexagonal layers. Further heating to 925–950 °C converts metakaolin to an aluminum-silicon spinel which is sometimes also referred to as a gamma-alumina type structure:



Upon calcination above 1050 °C, the spinel phase nucleates and transforms to platelet mullite and highly crystalline cristobalite:



Finally, at 1400 °C the "needle" form of mullite appears, offering substantial increases in structural strength and heat resistance. This is a structural but not chemical transformation. Kaolin is known to have the highest amount of alumina 35.6% % (A.O. Oladiji, & J.O. Borode., 2010) and 36.0% (Kirabira, 2005), which determines the refractoriness of a material. This makes the influence of kaolin on thermal conductivity value to be appreciable.

Quartz is the second most abundant mineral in the Earth's continental crust, after feldspar. It is made up of a continuous framework of SiO₄ silicon–oxygen tetrahedra, with each oxygen being shared between two tetrahedra, giving an overall formula SiO₂. There are many different varieties of quartz, several of which are semi-precious gemstones. Varieties of quartz have been since antiquity the most commonly used minerals in the making of jewelry and hard stone carvings. Quartz belongs to the trigonal crystal system. The ideal crystal shape is a six-sided prism terminating with six-sided pyramids at each end. In nature quartz crystals are often twinned, distorted, or so inter grown with adjacent crystals of quartz or other minerals as to only show part of this shape, or to lack obvious crystal faces altogether and appear

massive. Well-formed crystals typically form in a 'bed' that has unconstrained growth into a void; usually the crystals are attached at the other end to a matrix and only one termination pyramid is present. However doubly-terminated crystals do occur where they develop freely without attachment, for instance within gypsum. A quartz geode is such a situation where the void is approximately spherical in shape, lined with a bed of crystals pointing inward. α -quartz crystallizes in the trigonal crystal system, space group $P3_121$ and $P3_221$ respectively. β -quartz belongs to the hexagonal system, space group $P6_222$ and $P6_422$, respectively. These space groups are truly chiral (they each belong to the 11 enantiomorphous pairs). Both α -quartz and β -quartz are examples of chiral crystal structures composed of a chiral building block (SiO_4 tetrahedra in the present case). The transformation between α - and β -quartz only involves a comparatively minor rotation of the tetrahedra with respect to one another, without change in the way they are linked. Quartz crystals have piezoelectric properties; they develop an electric potential upon the application of mechanical stress. One of the most common piezoelectric uses of quartz today is as a crystal oscillator. The quartz clock is a familiar device using the mineral. The resonant frequency of a quartz crystal oscillator is changed by mechanically loading it, and this principle is used for very accurate measurements of very small mass changes in the quartz crystal microbalance and in thin-film thickness monitors. Its influence on thermal conductivity is not so significant since it has very low amount of alumina 0.7% (A.O. Oladiji & J.O. Borode, 2010).

The chemical composition of the clay determined by use of Atomic Absorption Spectrometry (AAS) (A.O. Oladiji & J.O. Borode, 2010) results were as shown in Table 2.2.

Table 2.1: Chemical composition of Kaolin, Feldspar, Ball clay and Quartz

Elements	Kaolin (%)	Ball Clay (%)	Quartz (%)	Feldspar (%)
SiO ₂	46.56	57.70	94.60	70.73
Al ₂ O ₃	35.60	32.50	0.70	16.42
TiO ₂	0.87	1.76	0.001	0.40
Fe ₂ O ₃	0.69	2.15	0.5	1.00
CaO	0.05	0.45	0.65	0.03
MgO	0.06	0.07	0.06	0.06
K ₂ O	0.70	2.30	0.30	0.30
Na ₂ O	0.08	0.08	0.40	0.07

2.3: Thermal Conduction by Ceramic Materials

Conduction is the transfer of heat through stationary matter by physical contact. (The matter is stationary on a macroscopic scale). Some materials conduct thermal energy faster than others. In general, good conductors of electricity (metals like copper, aluminum, gold, and silver) are also good heat conductors, whereas insulators of electricity (wood, plastic and rubber) are poor heat conductors. In a microscopic scale, conduction occurs as rapidly moving or vibrating atoms and molecules interact with neighboring particles, transferring some other kinetic energy. Heat is transferred by conduction when adjacent atoms vibrate against one another, or electrons move from one atom to another. Conduction is the most significant means of heat transfer within a solid or between solid objects in thermal contact. Conduction is greater in solids because the network of relatively close fixed spatial relationship between atoms helps to transfer energy between them by vibration. Fluids and gasses are less conductive than solids. This is due to the large distance between atoms in a fluid or (especially) a gas: fewer collisions between atoms means less conduction.

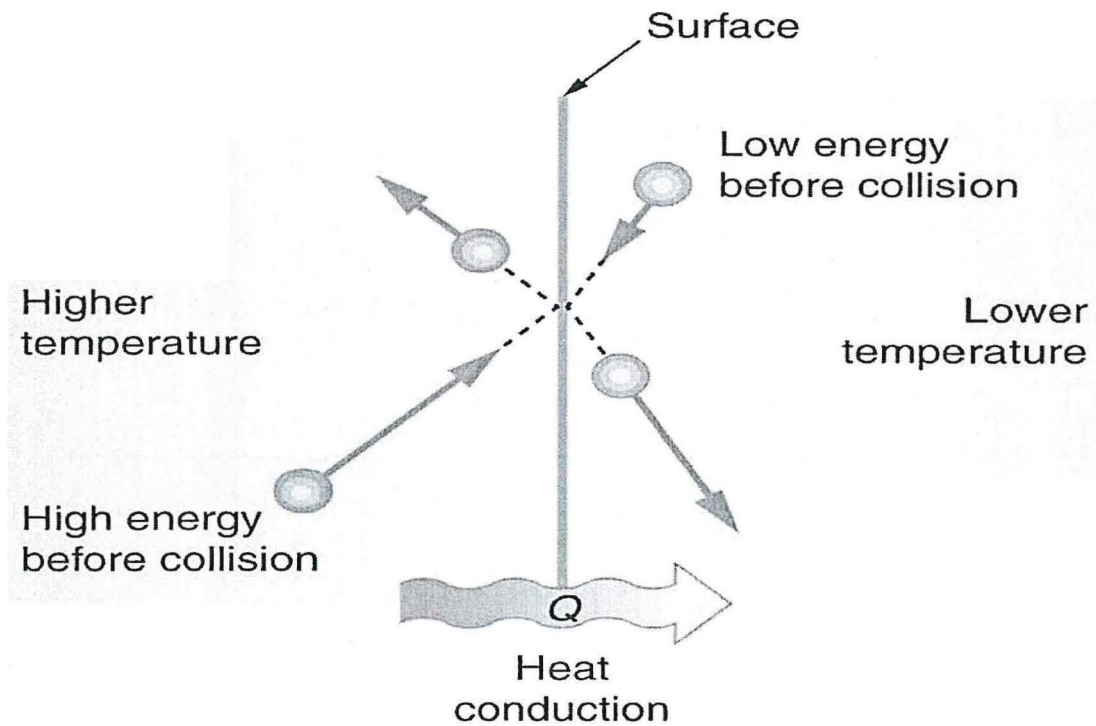


Figure 1.2: Microscopic Illustration of Thermal Conduction (from Brown. E 2001)

The average kinetic energy of a molecule in a hot body is higher than in the colder body. If two molecules collide, an energy transfer from the hot to the cold molecules occur (figure 2.4). The cumulative effect from all collisions results in a net flux of heat from a hot body to the colder body. The heat flux thus depends on the temperature difference $T = T_{\text{hot}} - T_{\text{cold}}$. Conversely, if the temperatures are the same, the net heat transfer rate falls to zero, and equilibrium is achieved. Owing to the fact that the number of collisions increase with increasing area, heat conduction depends on the cross-sectional area. An empirical relationship between the conduction rate in a material and the temperature gradient in the direction of energy flow was first formulated by Fourier in 1822. He stated that “the heat flux resulting from thermal conduction is proportional to the magnitude of the temperature gradient and opposite to it in sign” for a unidirectional conduction process this observation may be expressed as;

$$q_x = K \frac{dT}{dx} \dots\dots\dots(2.3)$$

Where the vector \mathbf{q}_x is the flux (Wm^{-2}) in the positive x-direction, dT/dx is the negative temperature gradient (Km^{-1}) in the direction of heat flow (i.e. conduction occurs in the direction of decreasing temperature and the minus sign confirms this thermodynamic axiom) and the constant of proportionality K is the thermal conductivity of the material ($\text{Wm}^{-1}\text{K}^{-1}$). Fourier's law provides the definition of thermal conductivity and forms the basis of many methods of determining its value. Fourier's law, as the basic rate equation of conduction process, when combined with the principle of conservation of energy, also forms the basis for analysis of most conduction problems.

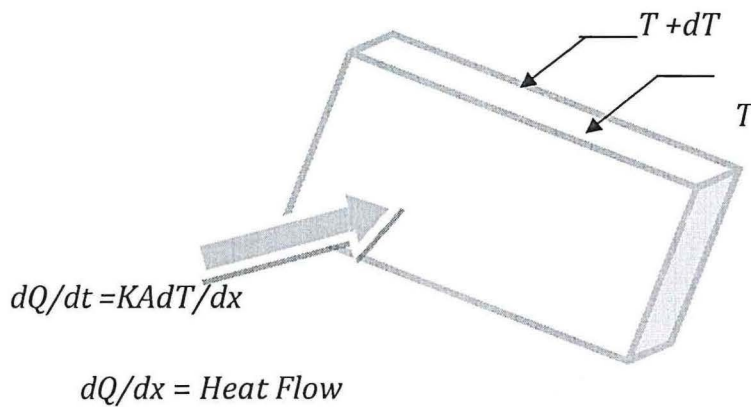


Figure 2.3: Fourier's homogenous solid to determine thermal conductivity

The proportionality ratio, K , is called thermal conductivity of the material. The lower the K -value for a material, the better it insulates. In addition to temperature and cross-sectional area, conduction is also affected by thickness of the material through which the heat transfers. Heat transfer from left side to right side is accomplished by a series of molecular collisions. The thicker the material, the more time it takes to transfer the same amount of heat.

2.5. Methods of Chemical Analysis

There are many methods used in analyzing of the chemical components of substances. The major ones are; - X-ray fluorescence spectroscopy (XRF), X-ray diffractometry

(XRD) and atomic absorption spectrometry (AAS). The one discussed in this research is XRF and XRD.

XRF is based on the principle that individual atoms, when excited by an external energy source, emit X-ray photons of a characteristic energy or wavelength. By counting the number of photons of energy emitted from a sample, the elements present may be identified and quantified. Modern XRF instruments are capable of analyzing solid, liquid, and thin-film samples for both major and trace (ppm-level) components. The analysis is rapid and usually sample preparation is minimal or not required at all.

The identification of elements by X-ray methods is possible due to the characteristic radiation emitted from the inner electronic shells of the atoms under certain conditions. The emitted quanta of radiation are X-ray photons whose specific energies permit the identification of their source atoms.

When an electron beam of high energy strikes a material, one of the results of the interaction is the emission of photons which have a broad continuum of energies. This radiation, called bremsstrahlung, or “braking radiation”, is the result of the deceleration of the electrons inside the material. The bremsstrahlung continuum is illustrated as a function of electron acceleration voltages for a molybdenum target in Figure 2.4.

Another result of the interaction between the electron beam and the material is the ejection of photoelectrons from the inner shells of the atoms making up the material. These photoelectrons leave with a kinetic energy ($E-\phi$) which is the difference in energy between that of the incident particle (E) and the binding energy (ϕ) of the atomic electron. This ejected electron leaves a “hole” in the electronic structure of the atom, and after a brief period, the atomic electrons rearrange, with an electron from a higher energy shell filling the vacancy. By way of this relaxation the atom undergoes *fluorescence*, or the emission of an X-ray photon whose energy is equal to the difference in energies of the initial and final states. Detecting this photon and measuring its energy allows us to determine the element and specific electronic

transition from which it originated (Jenkins 1988: 4-6, Anzelmo 1987 Part 1). Herein lies the basis for XRF spectrometry, where elements may be quantitated based on the rate of emission of their characteristic X-rays from a sample that is being excited.

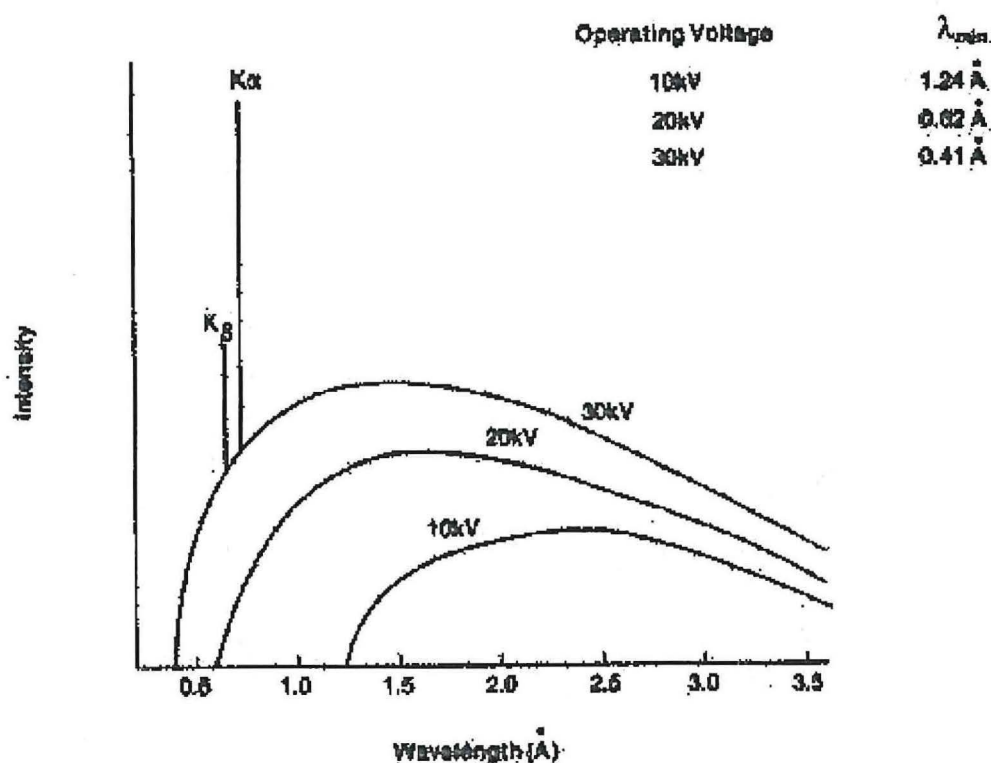


Figure 2.4. Intensity output from a Mo anode X-ray tube at different voltages (after Jenkins 1988: 5).

Any of the electrons in the inner shells of an atom can be ejected, and there are various electrons in the outer shells that can “drop” to fill the void. Thus there are multiple types of allowed transitions that occur which are governed by the laws of quantum mechanics, each transition having its own specific energy or line (Jenkins 1988: 6).

When X-rays impinge upon a material, besides being absorbed, causing electron ejection and subsequent characteristic photon emission, they may also be transmitted or scattered. When an X-ray is scattered with no change in energy this is called Rayleigh scattering, and when a random amount of energy is lost the phenomenon is Compton scattering. Scattered X-rays are usually problematic in XRF, creating high levels of background radiation (Anzelmo 1987 Part 1).

Since only the inner electron shells are involved in the emission of X-rays, the wavelengths are independent (within our ability to measure) of the state of chemical bonding, which involves the outer-most electron shells only. One exception to this rule involves low-Z elements with fewer electrons. The overall lack of chemical shifts allows the analyst to determine the elemental composition of the sample, whether the elements are present in their pure forms or as compounds (Skoog 1998: 275).

A diagram of a WD system is shown in Figure 2.5. The instrument operates based on the principle of Bragg diffraction of a collimated X-ray beam, in this case the beam emanating from the sample. A detector is angularly scanned relative to the analyzing crystal, registering the spectrum.

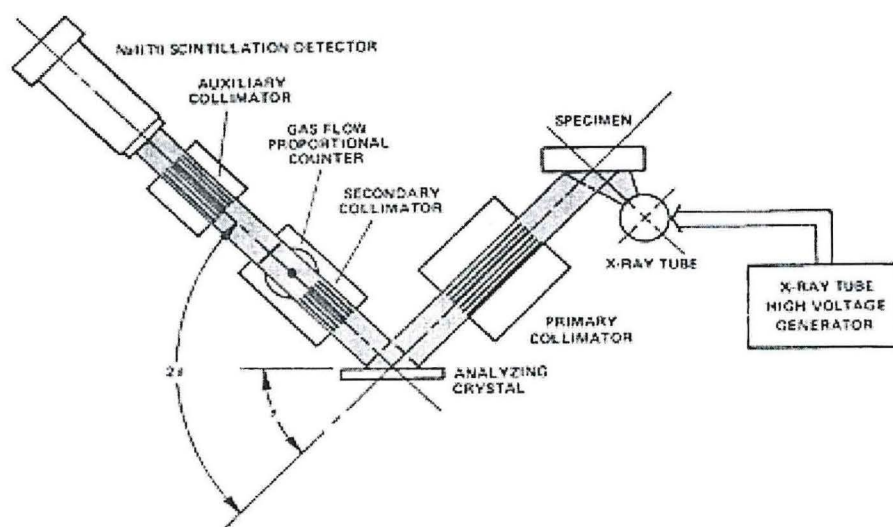


Figure 2.5: Diagram of a wavelength-dispersive spectrometer. (From Jenkins 1995: 88)

The two main types of XRF spectrometers (WD and ED) differ completely in their detection systems. EDXRF systems depend on semiconductor-type detectors which receive the entire emitted spectrum from the sample and decode it into a histogram of number of counts versus photon energy. WDXRF spectrometers, however, use an analyzing crystal to disperse the emitted photons based on their wavelength and place the detector in the correct physical location to receive X-rays of a given energy.

Sample preparation is highly variable depending on the matrix and goals of the analysis. Most of the materials we analyze (obsidian, metals, and ceramic paints) do not require any sample preparation. The choice of sample preparation depends on the nature of the X-ray beam relative to the sample. For example, a piece of obsidian that is 1 cm thick and has a clean, flat surface will provide ideal results. As samples get smaller, thinner, or less homogenous it is necessary to understand the nature of the X-ray beam and how it interacts with the sample.

For non-archaeological applications of XRF the most common method of sample prep is pelletizing, which can be made to work for most matrices that can be ground into a homogeneous powder, including soil, minerals, and dried organic matrices such as tissues or leaves. Difficult grinding is accomplished with a hard agate mortar and pestle but many samples can be adequately homogenized by placing into a hard plastic vial, adding a plastic mixing ball, and violently shaking in a mixer mill. A powdery binder containing cellulose, starch, polyvinyl alcohol or other organics is usually weighed in and blended thoroughly with the sample, and the resulting mixture added to a deformable aluminum cup. (Buhrke 1998) The sample and cup are pressed in a cylindrical die to form a supported pellet which ideally has a smooth, homogeneous sample surface and good physical stability.

Here particle size and homogeneity play a big factor. The thin surface layer must be representative of the bulk sample, and studies have shown that large errors (up to 50%) in quantization can occur for some elements when particle sizes exceed 50 μm . This is due to the variance in X-ray penetration depths with energy (Jenkins 1995: 281). Particles may be inhomogeneous also, having a different surface composition than their bulk. For example, copper sulfides may become partially oxidized at the surface, causing the relative absorption for Cu K lines to differ from that of the L lines. The L line photons will not penetrate as deeply and will tend to be emitted more from the oxide layer. By monitoring the ratio of the Cu $K\alpha$ line to the Cu $L\alpha$, the analyst can use this phenomenon to an advantage, allowing him or her to deduce some of the chemistry of the sample (Jenkins 2000).

One way to get around sample grinding is to fuse the sample at high temperatures with sodium or lithium tetra borate and then to pour this glass-like mixture into a mold (Buhrke: 41). Chemical reactions occur within the melt which dissolve particles and create a homogeneous liquid that hardens upon cooling. The disadvantages to this technique include the additional time to prepare the melt and the possibility of the sample reacting with even inert crucible materials such as platinum.

Currently XRF spectrometry is very widely applied in many industries and scientific fields. The steel and cement industries routinely utilize XRF devices for material development tasks and quality control. (Anzelmo 1987 Part 1) NIST utilizes XRF as one technique to quantitatively analyze and acceptance-test many of its standard reference materials (SRMs), from spectrometric solutions to diesel fuel to coal to metal alloys (Sieber 2000). The plastics industry is looking at a modified XRF spectrometer as an on-line wear monitor, taking advantage of its ability to detect particles of worn-off metal in extruded plastic pieces (Metz 1994). Polish scientists are accomplishing XRF analyses on very thin films by placing the source and detector at very low angles with respect to the sample. This technique is being applied to trace element determinations in water samples that have been evaporated to a thin film of residue (Holynska 1998).

XRD measurements are done at 2° per min scan rate operated at 30 KeV and 20 mA. After X-ray analysis of the samples, the analysis data is matched with the standard JCPDS software to identify the phases. X-ray diffraction is capable of providing general purpose qualitative and quantitative information on the presence of phases (e.g. compounds) in an unknown mixture. While it is true that techniques such as differential thermal analysis will provide some information on specific phase systems, under certain circumstances such methods could not be classified as general purpose. A diffraction pattern contains a great deal of information which include: the position of the diffraction maxima, the peak intensities, and the intensity distribution as a function of diffraction angle.

The three pieces of information can, in principle, be used to identify and quantify the contents of the sample, as well as to calculate the material's crystallite size and

distribution, crystallinity, stress and strain. The ideal specimen preparation for a given experiment depends largely on the information desired. A sample which is used only for the identification of its constituents may be quite different from a sample used to measure strain, which in turn may be different from a sample used in quantitative analysis. A diffraction pattern is characteristic of the atomic arrangement within a given phase and to this extent it acts as a *fingerprint* of that particular phase, (Nazaroff & Shackley, 2009).

Table 2.2 shows the chemical analysis of fired samples made by Bwayo in 2014 using the XRF method.

Table 2.2: Chemical composition of fired samples (adopted from Bwayo, 2014)

Compound	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	TiO ₂	Na ₂ O	MgO	K ₂ O	MnO ₂	P ₂ O ₅
Weight (%)	67.98	22.29	1.87	1.15	0.48	2.04	1.04	2.54	0.05	0.57

According to the Bureau of Energy Efficiency, India (2005), and United nation environmental programme-UNEP, (2006) reported on fireclay refractories, such as firebricks, siliceous fireclays and aluminous clay refractories to be consisting of aluminum silicates with varying silica (SiO₂) content of up to 78% and Al₂O₃ content of up to 44%. The melting point of fireclay brick decreases with increasing impurity and decreasing Al₂O₃ content (Table 2.3). This material is often used in furnaces, kilns and stoves because the materials are widely available.

Table 2.3: Properties of typical firebricks (adapted from Bureau of Energy Efficiency, (2005), ©UNEP, 2006).

Brick type	% SiO ₂	% Al ₂ O ₃	% of other constituents	Melting point (°C)
Super duty	49-53	40-44	5-7	1745-1760
High duty	50-80	35-40	5-9	1690-1745
Intermediate	60-80	26-36	5-9	1640-1680
High duty(siliceous)	65-80	18-30	3-8	1620-1680
Low density	60-70	23-33	6-10	1520-1595

2.6: Techniques of measurement of Thermal Conductivity of Materials

Steady state technique and non-steady state/transient technique are the two basic techniques employed in the measurement of thermal conductivity (Brown, M.E, 2001). The steady state technique performs measurement when material that is analyzed is in complete equilibrium. Poor conductors of heat, Lees' disc method can be used.

The methods discussed in this research are; - Searle's bar method, guarded hot plate, transient plane method and hot wire method.

Searle's bar method is an experimental procedure to measure thermal conductivity of material where a bar of material is being heated by steam on one side and the other side cooled down by water while the length of the bar is thermally insulated. Then the heat ΔQ propagating through the bar in a time interval of Δt is given by

$$\left(\frac{\Delta Q}{\Delta t}\right)_{bar} = -kA \frac{\Delta T_{bar}}{L} \dots\dots\dots (2.4)$$

Where

ΔQ Is the heat supplied to the bar in time Δt

K Is the coefficient of thermal conductivity of the bar

A Is the cross-sectional area of the bar.

ΔT_{bar} Is the temperature difference of both ends of the bar

L Is the length of the bar

And the heat ΔQ absorbed by water in a time interval of Δt is

$$\left(\frac{\Delta Q}{\Delta t}\right)_{water} = C_w \frac{\Delta m}{\Delta t} \Delta T_{water} \dots\dots\dots(2.5)$$

Where

C_w Is the specific heat capacity of water

Δm Is the mass of water collected during time Δt

ΔT_{water} Is the difference in the temperature of water before and after it has gone through the bar.

Assuming perfect insulation and no energy loss, then

$$\left(\frac{\Delta Q}{\Delta t}\right)_{bar} = \left(\frac{\Delta Q}{\Delta t}\right)_{water} \dots\dots\dots (2.6)$$

This leads to,

$$k = -C_w \frac{L \Delta_m \Delta T_{water}}{A \Delta t \Delta T_{bar}} \dots\dots\dots(2.7)$$

Transient plane source is a method that utilizes a plane sensor and a special mathematical model describing the heat conductivity, combined with electronics, enables the method to be used to measure thermal transport properties. It covers a thermal conductivity range of at least 0.01-500 W/m/k (in accordance with ISO 22007-2) and can be used for measuring various kinds of materials, such as solids, liquid, paste and thin film etc. In November 2008 it was approved as an ISO-standard for measuring thermal transport properties of polymers. This TPS standard also covers the use of this method to test both isotropic and anisotropic materials.

The transient plane source technique typically employs two samples halves, in-between which the sensor is sandwiched. Normally the samples should be homogenous, but extended use of transient plane source testing of heterogeneous material is possible with proper selection sensor size to maximize sample penetration. This method can also be used in a single-sided configuration, with the introduction of a known insulation material used as sensor support.

The physical model behind this method is the infinite line source with constant power per unit length. The temperature profile, $T(t, r)$ at a distance r at time t is given by:

$$T(t, r) = \frac{Q}{4\pi k} Ei\left(\frac{r^2}{4at}\right) \dots\dots\dots(2.8)$$

where: Q - is the power per unit length, in (Wm^{-1}), k is the thermal conductivity of the sample, in ($Wm^{-1}K^{-1}$), $Ei(x)$ - is the exponential integral, a transcendent mathematical function, r - is the radial distance to the line source, a - is the thermal diffusivity, in ($m^2 \cdot s^{-1}$), t - is the amount of time that has passed since heating started, in (s). When performing an experiment, one measures the temperature at a point at fixed distance,

and follows that temperature in time. For large times, the exponential integral can be approximated by making use of the following relation,

$$Ei(x) = -\gamma - \ln(x) + 0(x^2) \dots \dots \dots (2.9)$$

Where, $\gamma \approx 0.577$ is the Euler gamma constant,

This leads to the following expression;

$$T(t, r) = \frac{Q}{4\pi k} \left\{ -\gamma - \ln\left(\frac{r^2}{4a}\right) + \ln(t) \right\} \dots \dots \dots (2.10)$$

Note that the first two terms in the brackets on the right hand side are constants. Thus if the probe temperature is plotted versus the natural logarithm of time, the thermal conductivity can be determined from the slope, given the knowledge of Q . Typically this means ignoring the first 60 to 120 seconds of data and measuring for 600 to 1200 seconds, (Morriso, 2013)

Guarded hot plate is a widely used and versatile method for measuring the thermal conductivity of insulations. Although the specimens are often rather large, this usually presents no difficulty. A flat, electrically heated metering section surrounded on all lateral sides by a guard heater section controlled through differential thermocouples, supplies the planar heat source introduced over the hot face of the specimens. The most common measurement configuration is the conventional, symmetrically arranged guarded hot plate where the heater assembly is sandwiched between two specimens. In the single sided configuration, the heat flow is passing through one specimen and the back of the main heater acts as a guard plane creating an adiabatic environment.

This is an absolute method of measurement and its applicability requires the establishment of steady-state conditions, and the measurement of the unidirectional heat flux in the metered region, the temperatures of the hot and cold surfaces, the

thickness of the specimens and other parameters which may affect the unidirectional heat flux through the metered area of the specimen.

Three different categories of measurement systems can be distinguished: apparatus working around room temperatures, apparatus working below room temperatures (down to about -180°C), and apparatus working at high temperature (600°C or above). A given apparatus is most often best adopted for measurement in one of these temperature ranges.

Hot wire is another method which utilizes a heated wire inserted in to the material, the heat flows out radially from the wire into the sample and the temperature change in the wire is recorded (Santos, W.N.2002). The plot of wire temperature versus logarithm of time is used to calculate the thermal conductivity, provided the density and capacity are known. Since this is an intrusive measure, it works well for solid foams, fluids and melted plastics.

The hot wire method is a standard transient dynamic technique based on the measurement of the temperature rise in a defined distance from a linear heat source (hot wire) embedded in the test material. If the heat source is assumed to have a constant and uniform output along the length of test sample, the thermal conductivity can be derived directly from the resulting change in the temperature over a known time interval (Davis W.R., 1984). The hot wire uses the principle of transient hot wire method. Here the heating wire as well as the temperature sensor (thermocouple) is encapsulated in a probe that electrically insulates the hot wire and the temperature sensor from the test material (Wechsler A.E, 1992).

The ideal mathematical model of the method is based on the assumption that the hot wire is an ideal, infinite thin and long line heat source, which is in an infinite surrounding from homogenous and isotropic material with constant initial temperature. If q is the constant quantity of heat production per unit time per unit length of the heating wire (Wm^{-1}), initiated at the time $t=0$, the radial heat flow around the wire occurs.

Then the temperature rise $\Delta T(r,t)$ at radial position r from the heat source conforms to the formula.

$$\Delta T(r,t) = \frac{q}{4\pi k} \ln \frac{4at}{\sigma^2 C} \quad (2.12)$$

Where k is the thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$)

a is thermal diffusivity (m^2s^{-1}) ($a=k/rc_p$), σ being the density ($\text{kg}\cdot\text{m}^{-3}$) and C the heat capacity ($\text{Jkg}^{-1}\text{K}^{-1}$) of the test material a . The hot wire temperature rise reaches usually up to 10°C and its temperature evolution has typically the form as shown in Figure 2.6..

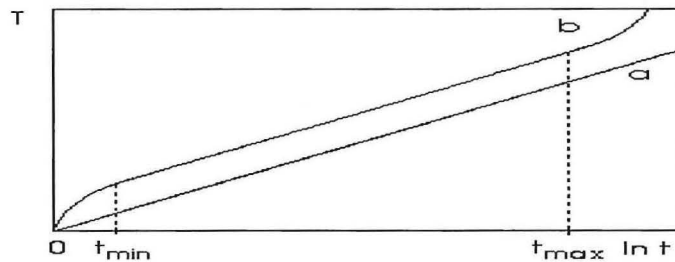


Figure 2.6: Typical temperature rise curve (a-ideal, b- non-ideal case)

Thermal conductivities of ceramic materials have been previously investigated by many people. Amongst those are;-

Mukwasibwe studied the thermal conductivity of fired clay samples from Seeta, Ntawo and Kigombya, using the Lee's Disk method and the values obtained were in the range of 0.13

-0.30 $\text{Wm}^{-1}\text{K}^{-1}$ at room temperature.

Owalu used the hot wire method to investigate the thermal conductivity of kaolin obtained from Buwambo quarry. Values obtained were in the range of 0.3- 1.5Wm⁻¹K⁻¹ at room temperature.

Bwayo used the quick thermal conductivity meter to determine the thermal conductivity of clay bricks made with different particle sizes from kaolin and ball clay, his results was in the range of 0.217-0.2409 Wm⁻¹K⁻¹

CHAPTER THREE: METHODOLOGY OF STUDY

3.1 Introduction

The main idea of obtaining better insulating clays materials was to have a formulation that has high percent of alumina (Al_2O_3). Powders of kaolin, ball clay, feldspar and quartz of uniform particle sizes were prepared. Kaolin, feldspar and quartz were collected from Mutaka in Bushenyi while ball clay was collected from Ntawo in Mukono. Sample clay were prepared in different proportions by weight of kaolin, ball clay, feldspar and quartz then dry pressed to 75MPa before firing to 1200°C. The thermal conductivity value was determined by use of Quick thermal conductivity meter (QTM-500) whose operation is based on the hot wire principle. Chemical composition of the mineral samples was determined by the x-ray fluoresces technique (XRF).

3.3 Sampling Technique

The sampling technique used for collecting the representative samples from their various deposits was purposive as described by (Tan, K.H., 2005). The clay minerals that were collected include: kaolin, feldspar and Quartz from Mutaka deposit in Bushenyi, ball clay from Ntawo deposit in Mukono. Mutaka kaolin is preferred because it has high content of alumina (36%), while Ntawo clay has (67.2%) silica which promotes sintering and bonding during firing, (Kirabira, 2005 and Olupot, 2010). Ntawo ball clay minerals have finite particle sizes, develop high plasticity and exhibit high mechanical strength when fired (Obwoya, 2004).

3.4 Materials Processing and Sieving

Kaolin was collected and soaked in water for seven days so that sand and roots settle at the bottom of the container. Kaolin was wet milled for 72 hours in a large ball mill to reduce particle size. It was then sun dried for seven days and further dried in oven at 110°C for five hours to remove all the free water. Dry sieving was done by use of a mechanical test sieve shaker to size of 45µm and stored in a clean plastic bag with a label.

Feldspar was dry milled using a ball mill for 36 hours. Slurry from the mill was then sieved to particle size of $45\mu\text{m}$. This was also packed in to special plastic bag and labeled.

Ball clay was soaked in water and allowed to settle and then sieved to particle size of $45\mu\text{m}$. Then packed in plastic bag and given a label.

The Quartz minerals was wet milled for four days running for 7 hours each day at a speed of 50 rev/min. this was poured in to plaster of Paris (PoP) mould to remove the excess water and the semi-dry cast was left to dry in air. There after transferred in to a drying oven at a temperature of 105°C to be sure that all the trapped water in the pores of clay was driven off. It was then sieved to sizes of $45\mu\text{m}$ and stored in clean polythene bag and labeled. Equal particle size of all the minerals was used to ensure uniform particle parking and uniform density of the sample during pressing.



Figure 3.1: Sieves on a mechanical vibrator

3.5: Formulation of Test Specimens

For each sample formed, the four mineral types were mixed together by varying the proportion of only one of the minerals, the other three composed of the same proportion. Weighing each mineral was done independently but the total weight of the four minerals mixed together in each sample was made to 100g. Each mixture was poured in a mortar mixer which is made of cylindrical can and thoroughly mixed. This is because each sample composed of four minerals in varying proportions, so for uniformity purpose and effective blend would require it thoroughly mixed.

In the first part of the study the batch formulations A₁ to D₁ had compositions of kaolin, ball clay, Feldspar kept at fixed amounts but varying that of Quartz as shown in Table 3.1

Table 1.1: Samples made with varying ratios of Quartz

CLAY MINERALS	COMPOSITION OF SAMPLES (%) (TOTAL WT=100g)			
	A ₁	B ₁	C ₁	D ₁
Kaolin	15	20	25	30
Feldspar	15	20	25	30
Ball clay	15	20	25	30
Quartz	55	40	25	10
Total	100	100	100	100

In the second part of the study the batch formulations A₂ to D₂ had compositions of kaolin, Quartz, Feldspar kept at fixed amounts but varying that of ball clay as shown in Table 3.2

Table 3.2: Samples made with varying ratios of Ball clay

CLAY MINERALS	COMPOSITION OF SAMPLES (%) (TOTAL WT=100g)			
	A ₂	B ₂	C ₂	D ₂
Kaolin	15	20	25	30
Feldspar	15	20	25	30
Ball clay	55	40	25	10
Quartz	15	20	25	30
Total	100	100	100	100

In the third part of the study the batch formulations A₃ to D₃ had compositions of kaolin, Quartz, ball clay kept at fixed amounts but varying that of Feldspar as shown in Table 3.3

Table 3.3: Samples made with varying ratios of Feldspar

CLAY MINERALS	COMPOSITION OF SAMPLES (%) (TOTAL WT=100g)			
	A ₃	B ₃	C ₃	D ₃
Kaolin	15	20	25	30
Feldspar	55	40	25	10
Ball clay	15	20	25	30
Quartz	15	20	25	30
Total	100	100	100	100

In the fourth part of the study the batch formulations A₄ to D₄ had compositions of Feldspar, Quartz, and Ball clay kept at fixed amounts but varying that of kaolin as shown in Table 3.4

Table 3.4: Samples made with varying ratios of kaolin

CLAY MINERALS	COMPOSITION OF SAMPLES (%) (TOTAL WT=100g)			
	A ₄	B ₄	C ₄	D ₄
Kaolin	55	40	25	10
Feldspar	15	20	25	30
Ball clay	15	20	25	30
Quartz	15	20	25	30
Total	100	100	100	100

In the fifth part of the study the batch formulations A₅ to D₅ had compositions of Feldspar, Quartz, Ball clay and kaolin all varied as shown in Table 3.5

Table 3.5: Samples made with varying the entire mineral ratios

CLAY MINERALS	COMPOSITION OF SAMPLES (%) (TOTAL WT=100g)			
	A ₅	B ₅	C ₅	D ₅
Kaolin	10	20	30	40
Feldspar	20	30	40	10
Ball clay	30	40	10	20
Quartz	40	10	20	30
Total	100	100	100	100

3.6: Formation of the Green Body

100g of each sample formulation was weighed using a digital balance and put in a rectangular mold and then compacted to a pressure of 75MPa using the hydraulic press machine to form rectangular clay samples of dimensions 100mm x 50mm x 10mm. The sample was compacted slowly and gently using a hydraulic press machine to stabilize pressure and avoid cracking of the samples during firing. When the set pressure was reached, it was maintained for about 5 minutes to allow the pressure to stabilize. The press force was then released slowly to avoid sudden expansion and the mold removed.

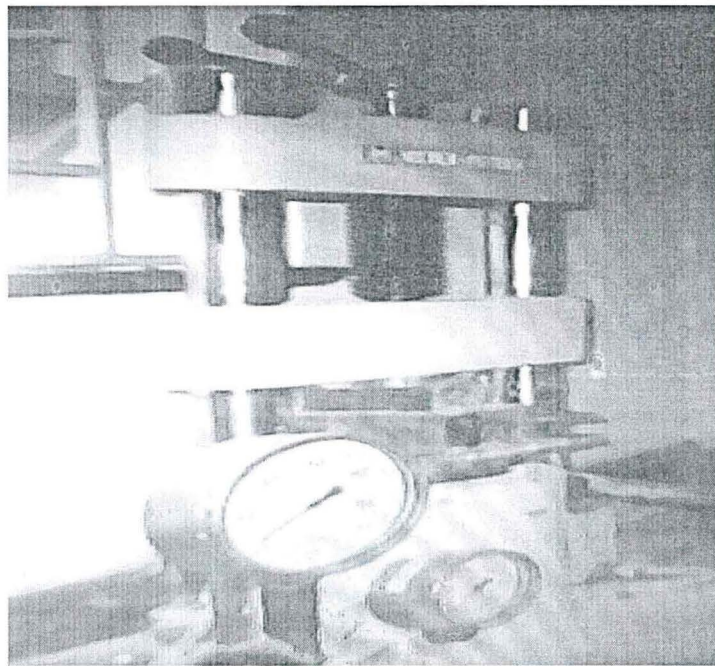


Figure 3.2: Hydraulic press machine PW-40

3.7: Firing

The clay samples produced were fired to a peak temperature of 1200°C at a rate of 100°C per hour. However, in the beginning, ordinary water was driven off by holding it at a temperature of 105°C for two hours and also at 250°C to remove hydroxyl ions. After this temperature, the specimen was fired under controlled temperatures up to peak value. The holding time was one hour before the furnace

was switched off to allow the samples cool naturally to room temperature, (Olupot, 2010).

3.8: Experimental measurements

3.8.1: Chemical Characterization of Mineral Samples

Thermal conductivity of ceramic materials among other factors is affected by mineral and chemical composition of the raw materials. This study found it necessary to determine the chemical composition of the clay minerals used in the study. The chemical compositions of the four minerals used were determined by the X-ray fluorescence (XRF) spectrometer. The percentage compositions of each sample were calculated from the averages of the percentage values of three samples for each mineral (appendix B).

Table 3.6: Chemical composition of Kaolin, Feldspar, Ball clay and Quartz

Elements	Kaolin (%)	Ball Clay (%)	Quartz (%)	Feldspar (%)
Al ₂ O ₃	39.80	30.05	2.01	17.41
SiO ₂	54.50	63.60	91.80	78.0
TiO ₂	0.19	0.56	0.14	0.30
Fe ₂ O ₃	0.67	1.08	1.60	0.90
CaO	0.75	0.43	0.53	0.07
MgO	0.24	0.22	0.07	0.07
K ₂ O	1.80	2.39	2.41	0.84
Na ₂ O	0.89	0.67	0.56	0.90
MnO ₂	0.20	0.80	0.64	0.64
P ₂ O ₅	0.96	0.20	0.24	0.87

3.8.2: Measurement of Thermal Conductivity

The Quick thermal conductivity meter (QTM-500) which uses the hot wire method was used in this study. It does quick and easy measurement on all kinds and types of sample materials. The QTM-500 has a sensor probe which consists of a constantan wire heater and a thermocouple. The heating wire is used to supply heat to the test sample and the thermocouple monitors the heat flow rate.

The measurement of thermal conductivity was done by placing the rectangular block sample in the probe box and then placing the sensor probe (PD-11) on sample surface (figure 3.3).

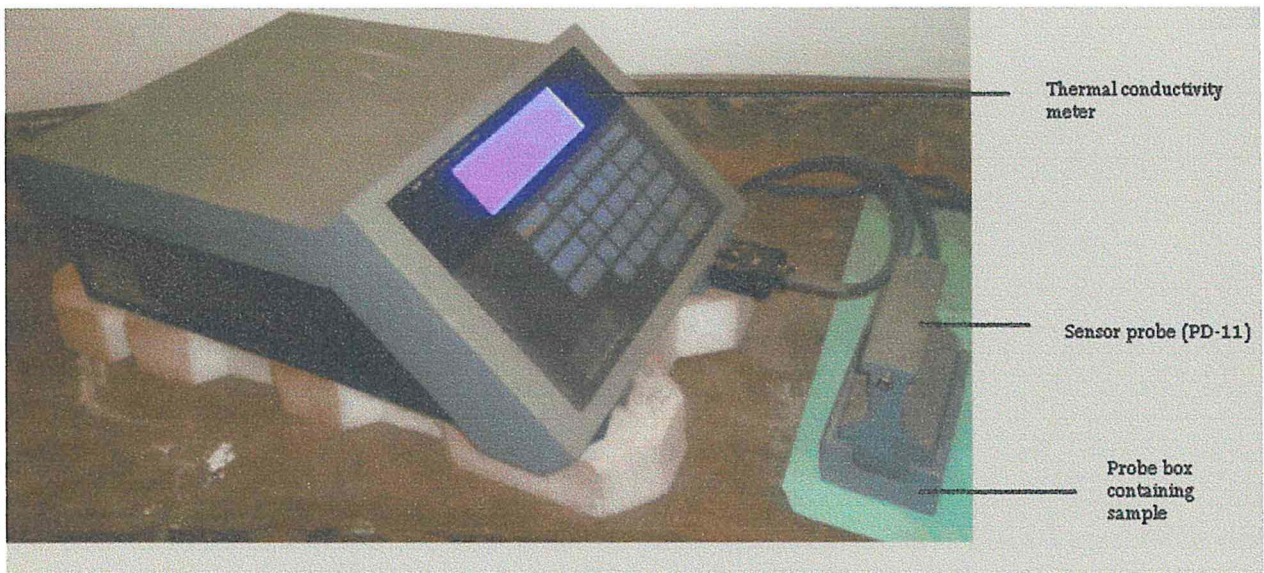


Figure 3.3: Experimental set up used for thermal conductivity measurement

The QTM was switched on. The meter displayed Meas. wait on the LCD displayed for around 3 minutes till the temperature of the probe was in equilibrium with that of the sample. An alarm was made and the start button was then pressed. During the measurement, temperature of the wire against time curve was plotted on the

display automatically. After 60s, the graph was complete then another alarm was heard and the value of thermal conductivity displayed on the screen which was recorded. Each formulation had three samples whose thermal conductivity values were measured and the averages obtained and recorded (appendix A).

CHAPTER FOUR: RESULTS OF STUDY

4.1 Introduction

In this chapter the results of the study were presented. The results described information on the step by step procedures of experiments.

In addition, the results indicated the relationships between variables provided from the tests performed.

4.2 Thermal Conductivity of clay with varied Quartz

The measured thermal conductivity values for clay samples made by varying ratios of quartz is as presented in Table 4.1 .All measurements were carried out at room temperature (approximately 25°C).

Table 4.1: Thermal conductivity of the samples made with varying ratios of Quartz

Minerals	Composition of samples (%) (total wt=100g)			
	A ₁	B ₁	C ₁	D ₁
Kaolin	15	20	25	30
Feldspar	15	20	25	30
Ball clay	15	20	25	30
Quartz	55	40	25	10
Thermal conductivity (±0.0005Wm⁻¹K⁻¹)	0.3320	0.3319	0.3308	0.3305

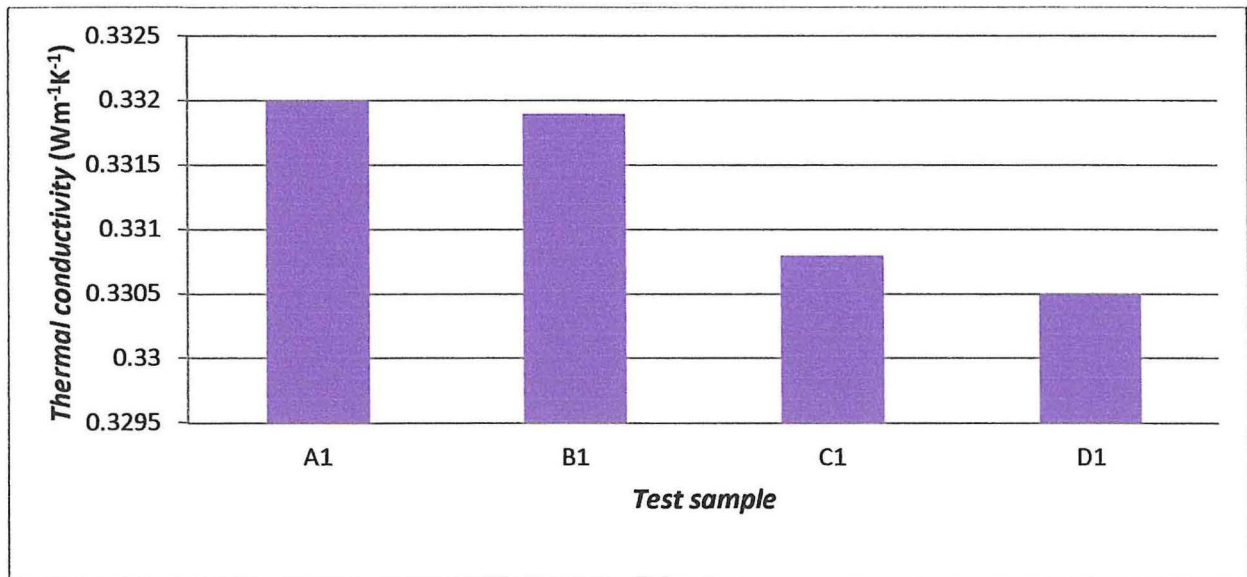


Figure 4.1: Bar chart of thermal conductivity for change in mineral composition of Quartz

The graph in figure 4.1 above has given the thermal conductivity values for varying the percentage of quartz as $0.3320 \text{ Wm}^{-1}\text{K}^{-1}$, $0.3319 \text{ Wm}^{-1}\text{K}^{-1}$, $0.3308 \text{ Wm}^{-1}\text{K}^{-1}$ and $0.3305 \text{ Wm}^{-1}\text{K}^{-1}$ for A₁, B₁, C₁ and D₁ respectively.

4.3 Thermal Conductivity of clay with varied Ball clay

Table 4.2: Thermal conductivity of the samples made with varying ratios of Ball clay

Minerals	Composition of samples (%) (total wt=100g)			
	A ₂	B ₂	C ₂	D ₂
Kaolin	15	20	25	30
Feldspar	15	20	25	30
Ball clay	55	40	25	10
Quartz	15	20	25	30
Thermal conductivity ($\pm 0.0005 \text{ Wm}^{-1}\text{K}^{-1}$)	0.3225	0.3229	0.3263	0.32677

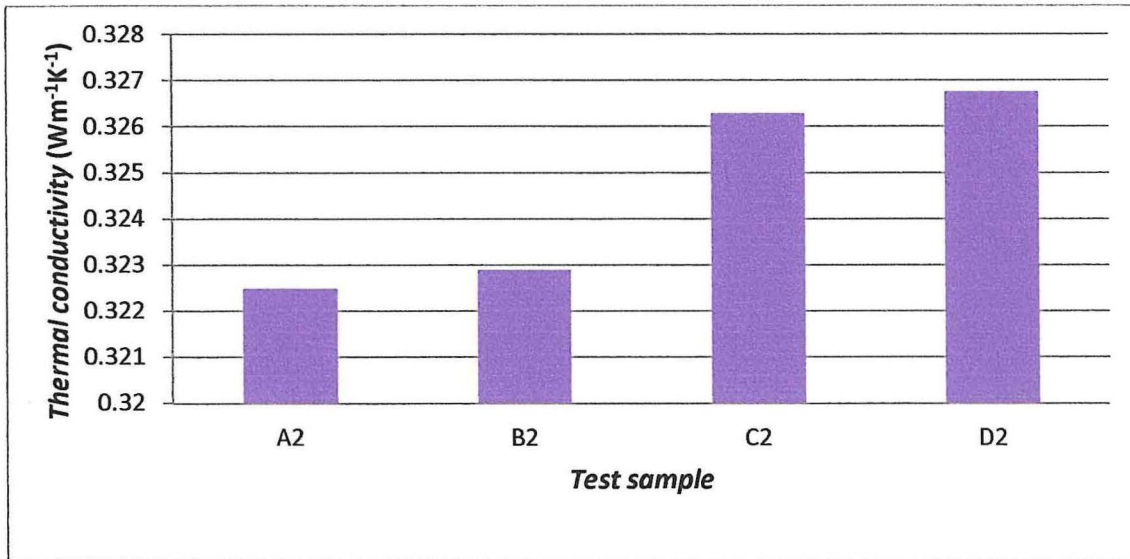


Figure 4.2: Bar chart of thermal conductivity for change in mineral composition of Ball clay

The graph in figure 4.2 above has given the thermal conductivity values for varying the percentage of ball clay as $0.3225 \text{ Wm}^{-1}\text{K}^{-1}$, $0.3229 \text{ Wm}^{-1}\text{K}^{-1}$, $0.3263 \text{ Wm}^{-1}\text{K}^{-1}$ and $0.3267 \text{ Wm}^{-1}\text{K}^{-1}$ for A_2 , B_2 , C_2 and D_2 respectively.

4.4 Thermal Conductivity of clay with varied Feldspar

Table 4.3: Thermal conductivity of the samples made with varying ratios of Feldspar

Minerals	Composition of samples (%) (total wt=100g)			
	A ₃	B ₃	C ₃	D ₃
Kaolin	15	20	25	30
Feldspar	55	40	25	10
Ball clay	15	20	25	30
Quartz	15	20	25	30
Thermal conductivity ($\pm 0.0005 \text{ Wm}^{-1}\text{K}^{-1}$)	0.3313	0.3295	0.3287	0.3274

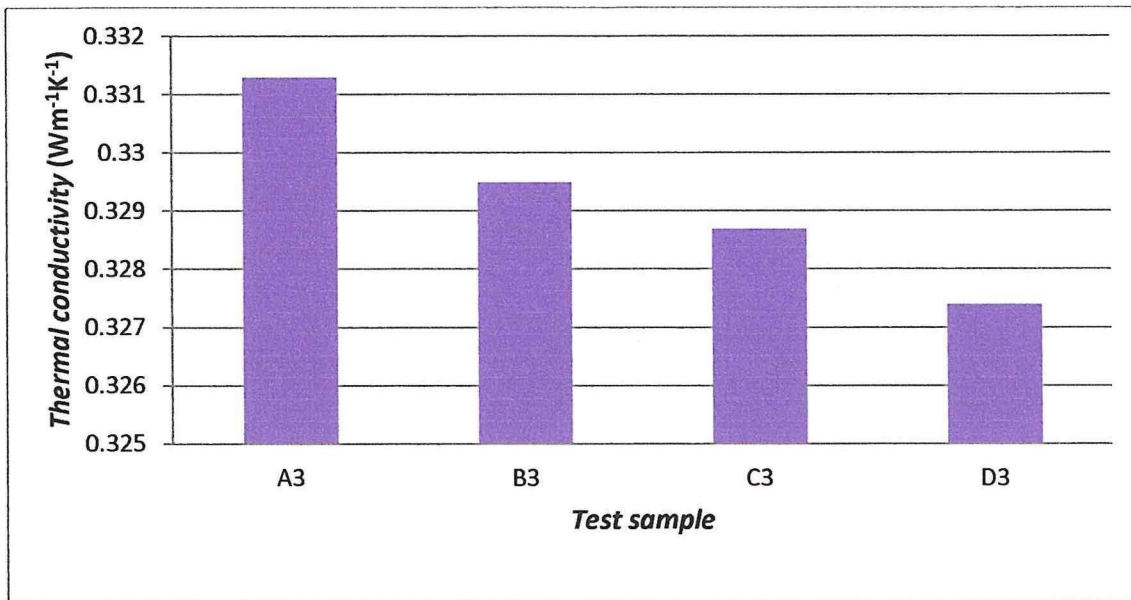


Figure 4.3: Bar chart of thermal conductivity for change in mineral composition of Feldspar

The graph in figure 4.3 above has given the thermal conductivity values for varying the percentage of feldspar as $0.3313 \text{ Wm}^{-1}\text{K}^{-1}$, $0.3295 \text{ Wm}^{-1}\text{K}^{-1}$, $0.3287 \text{ Wm}^{-1}\text{K}^{-1}$ and $0.3274 \text{ Wm}^{-1}\text{K}^{-1}$ for A₃, B₃, C₃ and D₃ respectively.

4.5 Thermal Conductivity of clay with varied kaolin

Table 4.4: Thermal conductivity of the samples made with varying ratios of Kaolin

Minerals	Composition of samples (%) (total wt=100g)			
	A ₄	B ₄	C ₄	D ₄
Kaolin	55	40	25	10
Feldspar	15	20	25	30
Ball clay	15	20	25	30
Quartz	15	20	25	30
Thermal conductivity ($\pm 0.0005 \text{ Wm}^{-1}\text{K}^{-1}$)	0.3179	0.3235	0.3264	0.3280

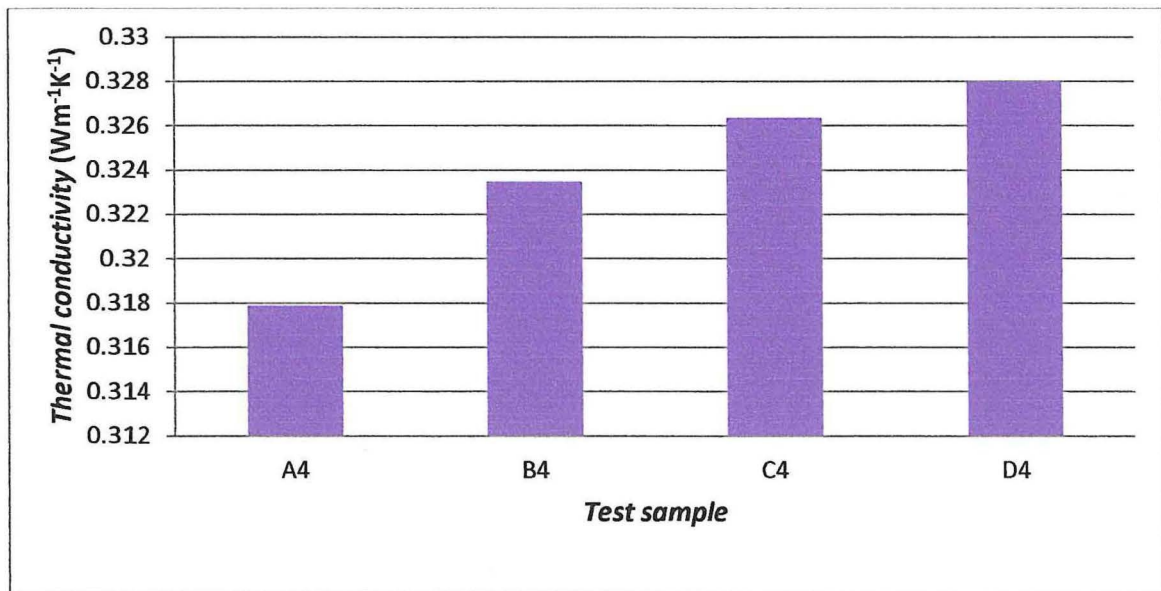


Figure 4.4: Bar chart of thermal conductivity for change in mineral composition of Kaolin

The graph in figure 4.4 above has given the thermal conductivity values for varying the percentage of feldspar as $0.3179 \text{ Wm}^{-1}\text{K}^{-1}$, $0.3235 \text{ Wm}^{-1}\text{K}^{-1}$, $0.3264 \text{ Wm}^{-1}\text{K}^{-1}$ and $0.3280 \text{ Wm}^{-1}\text{K}^{-1}$ for A₄, B₄, C₄ and D₄ respectively.

4.6: Thermal Conductivity of clay with varying the ratios of all the minerals

Table 4.5: Thermal conductivity of the samples made with varying all the mineral ratios

Minerals	Composition of samples (%) (total wt=100g)			
	A ₅	B ₅	C ₅	D ₅
Kaolin	10	20	30	40
Feldspar	20	30	40	10
Ball clay	30	40	10	20
Quartz	40	10	20	30
Thermal conductivity Wm⁻¹K⁻¹)	0.3288	0.3274	0.3290	0.3239

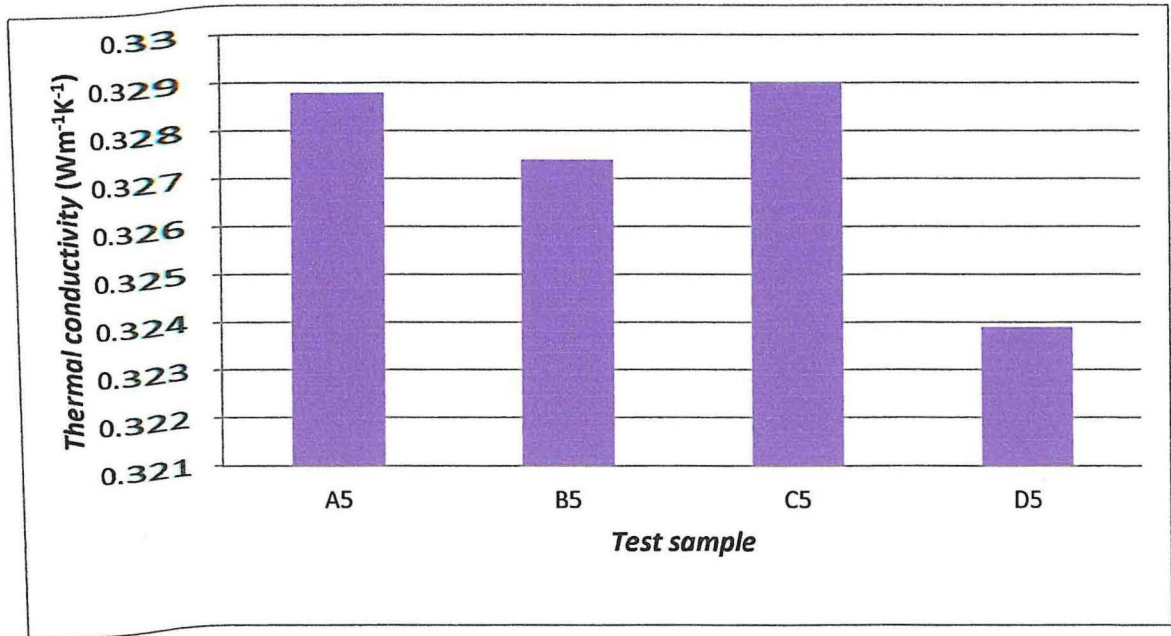


Figure 4.5: Bar chart of thermal conductivity for change in all mineral composition

The graph in figure 4.5 above has given the thermal conductivity values for varying the percentage of all the minerals as 0.3288 Wm⁻¹K⁻¹, 0.3274 Wm⁻¹K⁻¹, 0.3290 Wm⁻¹K⁻¹ and 0.3239 Wm⁻¹K⁻¹ for A₄, B₄, C₄ and D₄ respectively.

The entire results plotted in figures 4.1, 4.2, 4.3, 4.4 and 4.5 was then summarized on the same axis as indicated in figure 4.6 below, in order to see the general trend.

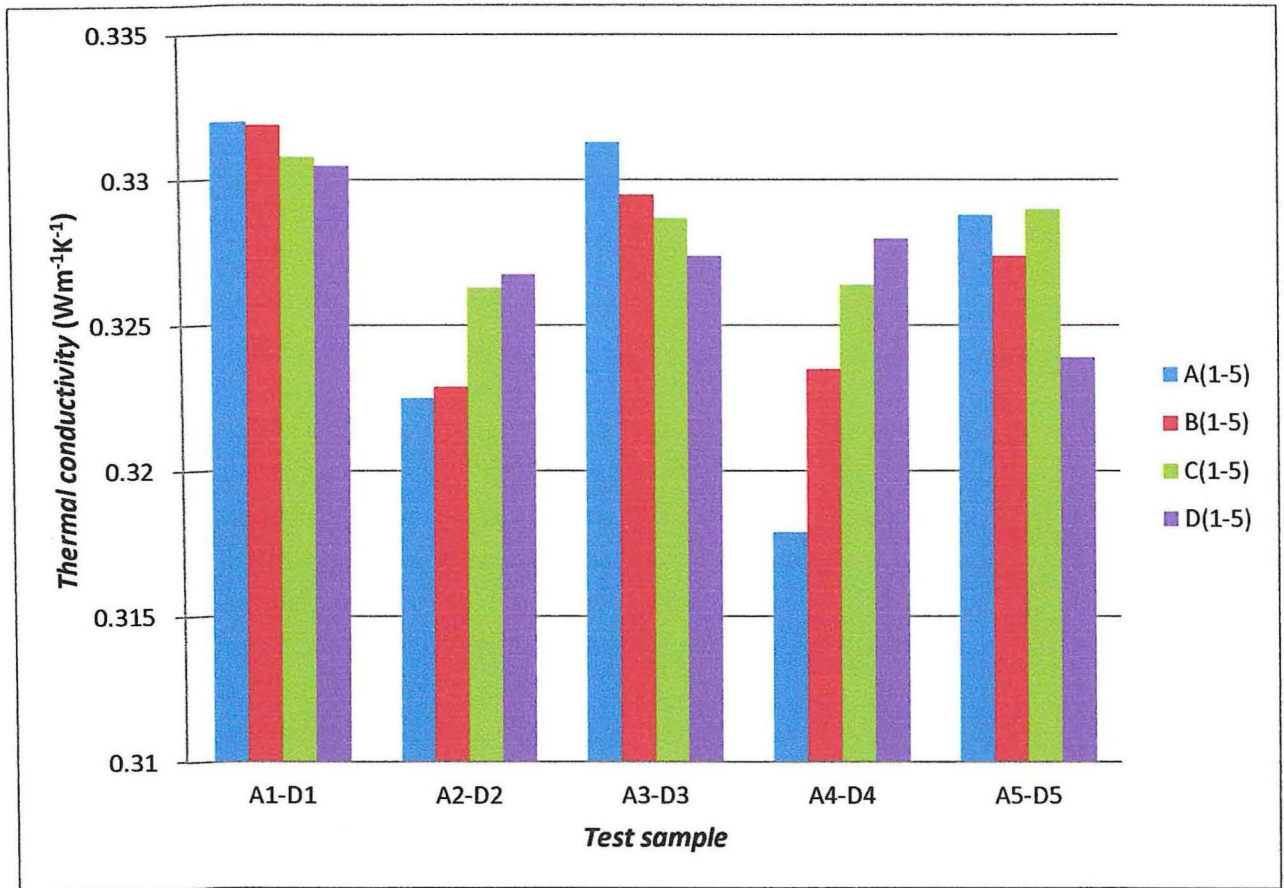


Figure 4.6: Bar chart of thermal conductivity for different mineral formulations

The graph in figure 46 above has given the thermal conductivity values for varying the percentage of all the four minerals on the same axes. The highest thermal conductivity value was $0.3320 \text{ Wm}^{-1}\text{K}^{-1}$ (Quartz-55%, Ball clay-15%, Feldspar-15%, and Kaolin-15%) and the lowest thermal conductivity value was $0.3179 \text{ Wm}^{-1}\text{K}^{-1}$ (Quartz-15%, Ball clay-15%, Feldspar-15%, and Kaolin-55%).

CHAPTER FIVE: DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussions

The measured thermal conductivity values in table 4.1 and plotted data in figure 4.1 showed that thermal conductivity value decreased as the amount of quartz decreased in each pieces from A₁-D₁. The highest thermal conductivity value was $3.32 \times 10^{-1} \text{Wm}^{-1}\text{K}^{-1}$ in A₁ and the lowest value $3.305 \times 10^{-1} \text{Wm}^{-1}\text{K}^{-1}$ in D₁. This is because the insulation property of any clay material is determined by the amount of alumina (Al₂O₃) in that material. A₁ had the lowest percentage by mass of Alumina in the entire formulation of 14.1%, while D₁ composed of 26.38% of alumina (appendix D). This result is also in close agreement with the findings of Owalu from Makerere University, who in 2008 used the hot wire method to investigate the thermal conductivity of kaolin obtained from Buwambo quarry near Kampala, the results obtained at room temperature was in the range of 0.3- 1.5Wm⁻¹K⁻¹. The composition of alumina in the sample D₁ also complies with percentage of alumina in low density insulation bricks (UNEP, 2006).

The values of thermal conductivity in Table 4.2 and the plot in Figure 4.2 clearly relate the effect of varying the composition of ball clay on the thermal conductivity. The composition A₂ with the highest percent of alumina (25.42%) had the lowest thermal conductivity value of $0.3225 \text{Wm}^{-1}\text{K}^{-1}$, while D₂ with lowest percent of alumina (20.77%) had the highest thermal conductivity value of $0.3268 \text{Wm}^{-1}\text{K}^{-1}$ (appendix D). This result is also in consistence with the finding of Ayugi from Makerere University who, in 2001 used QTM-500 to measure thermal conductivity of clay at compaction pressure of 72.9MPa. Her result was in the range 0.285- 0.308 Wm⁻¹K⁻¹.

Results in table 4.3 and the graph in Figure 4.3 have shown a great impact in the thermal conductivity value as a result of change in the composition of feldspar. The result showed that, as the composition of feldspar increased, so did the thermal conductivity value. The attribution is majorly due to low percent of alumina in A₃ (20.36%) causing it to have slightly lower value of thermal conductivity compared to D₃ with 23.3% of alumina (appendix D).

Results in table 4.4 and the graph in Figure 4.4 described the effect of variation in composition of kaolin on the thermal conductivity values. It showed that, as the amount of kaolin in the mixture increased, the thermal conductivity value decreased. This is because kaolin according to chemical analysis in table 3.7 is the mineral with the highest percent of alumina, which is responsible for provision of as much insulation as possible in ceramic bodies. This formulation had pieces that had the lowest thermal conductivity value of $0.3179 \text{ Wm}^{-1}\text{K}^{-1}$ in the entire experiment done.

Table 4.5 and the Figure 4.5 also showed that, the samples that had got high proportion of alumina (D₅) had the lowest value of thermal conductivity of $0.324 \text{ Wm}^{-1}\text{K}^{-1}$, while the samples A₅ had the highest value of thermal conductivity of $0.329 \text{ Wm}^{-1}\text{K}^{-1}$ (appendix D)

When the individual graphs in figures 4.1, 4.2, 4.3, 4.4 and 4.5 were plotted on the same axes as seen in Figure 4.6, it was seen that the lowest thermal conductivity value in the entire study was $3.179 \times 10^{-1} \text{ Wm}^{-1}\text{K}^{-1}$ with composition of (Quartz-15%, Ball clay-15%, Feldspar-15%, and Kaolin-55%) and this was obtained in the formulation that had the proportion of kaolin being varied. While the highest thermal conductivity value was $3.32 \times 10^{-1} \text{ Wm}^{-1}\text{K}^{-1}$ (Quartz-55%, Ball clay-15%, Feldspar-15%, and Kaolin-15%) was attained in the formulation which had the composition of Quartz varied.

5.2 Conclusions

The results showed that all the samples studied have fairly low thermal conductivities; hence the rate of heat transfer in these samples is low. The thermal conductivity values ranged from 3.179×10^{-1} to $3.32 \times 10^{-1} \text{ Wm}^{-1}\text{K}^{-1}$. These low values of thermal conductivity are characteristic of good thermal insulators.

Thermal conductivity was directly affected by mineral composition, however best insulators was realized when the percent of kaolin and ball clay in them are high, since this minerals have got the highest percentage of alumina in them as per chemical analysis.

The most suitable composition for thermal insulation was the sample containing a mixture of kaolin-55%, Feldspar-15%, Ball clay-15% and Quartz-15%, all these minerals had the same particle size of 45 μ m, firing pressure of 75MPa. This combination was characterized by the lowest value of the thermal conductivity of $3.179 \times 10^{-1} \text{ Wm}^{-1}\text{K}^{-1}$

5.2 Recommendations

Basing on the scope of the parameters study, certain unconsidered parameters are worth considering. Therefore the following recommendations are suggested for consideration with respect to the unconsidered parameters:-

- i. This study covered minerals with fixed particle sizes; fixed compression pressure and fixed firing temperatures, other particle sizes, compression pressure and firing temperatures should be investigated.
- ii. The use of other organic wastes like, coffee husks, rice husks, groundnuts husks by introducing in to the sample should be investigated for production of thermal insulation clay.
- iii. The effect of increasing the concentration of only one mineral should be considered.

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APPENDIX A

THERMAL CONDUCTIVITY MEASUREMENTS RESULTS

Sample made with varying ratios of Quartz

		Length (m)	Width (m)	Height (m)	M(g)	M(kg)	Area(m ²)	T.C (Wm ⁻¹ K ⁻¹)	ST.DEV (Wm ⁻¹ K ⁻¹)	t- _v
AI	1	0.0973	0.0400	0.012	87.15	0.08715	0.00048	0.33021235		
	2	0.1005	0.0401	0.011	79.57	0.07957	0.000441	0.331691535	0.002005	
	3	0.1076	0.0411	0.0104	82.21	0.08221	0.000427	0.334180238		
Average								0.332028041		
BI	1	0.0887	0.0373	0.011	78.48	0.07848	0.00041	0.330720371		
	2	0.1047	0.0446	0.0134	80.44	0.08044	0.000598	0.334915809	0.002564	0.1
	3	0.0993	0.0416	0.0107	85.11	0.08511	0.000445	0.330263056		
Average								0.331966412		
CI	1	0.0724	0.0441	0.0116	50.09	0.05009	0.000512	0.328650961		
	2	0.1066	0.0446	0.0055	74.56	0.07456	0.000245	0.331794218	0.001945	0.3
	3	0.1051	0.0443	0.0105	82.91	0.08291	0.000465	0.332205823		
Average								0.330883667		
DI	1	0.0902	0.0383	0.0137	84.06	0.08406	0.000525	0.327208448		
	2	0.1036	0.0427	0.0088	75.94	0.07594	0.000376	0.329706461	0.003817	0.1
	3	0.104	0.0439	0.0099	77.61	0.07761	0.000435	0.334705192		
Average								0.330540032		

Samples made with varying ratios of Ball Clay

Samples		L (m)	W (m)	H (m)	M(g)	M(kg)	A(m ²)	T.C (Wm ⁻¹ k ⁻¹)	ST.DEV (Wm ⁻¹ K ⁻¹)	t-value
AII	1	0.0816	0.0341	0.0133	80.65	0.08065	0.000454	0.321937366		
	2	0.0761	0.0311	0.0112	75.95	0.07595	0.000348	0.321135985	0.001795	
	3	0.0798	0.0345	0.0133	75.03	0.07503	0.000459	0.324567887		
Average								0.322547079		
BII	1	0.0783	0.0313	0.0149	81.29	0.08129	0.000466	0.318121234		
	2	0.0835	0.0341	0.0172	87.12	0.08712	0.000587	0.321842803	0.00553	0.1315
	3	0.0834	0.0348	0.0147	81.69	0.08169	0.000512	0.329001766		
Average								0.322988601		
CII	1	0.0896	0.0372	0.0135	83.36	0.08336	0.000502	0.323317091		
	2	0.0887	0.0373	0.0156	82.66	0.08266	0.000582	0.325198255		
	3	0.0893	0.0372	0.0132	85.27	0.08527	0.000491	0.330415302		
									0.003677	0.8660
Average								0.326310216		
DII	1	0.0953	0.0404	0.0116	83.61	0.08361	0.000469	0.328500929		
	2	0.0939	0.0401	0.0133	84.19	0.08419	0.000533	0.325929772	0.001499	0.2007
	3	0.0938	0.0401	0.0073	59.14	0.05914	0.000293	0.325880864		
Average								0.326770521		

Samples made with varying ratios of Feldspar

		L(m)	W(m)	H(m)	M(g)	M(kg)	A(m ²)	T.C (Wm ⁻¹ k ⁻¹)	ST.DEV (Wm ⁻¹ K ⁻¹)	t-valu
AIII	1	0.0912	0.0377	0.0137	84.82	0.08482	0.000516	0.327902668		
	2	0.0912	0.0384	0.0157	83.2	0.0832	0.000603	0.328002171	0.000801	
	3	0.0897	0.0366	0.0134	79.87	0.07987	0.000490	0.326567400		
Average								0.331349735		
BIII	1	0.1031	0.0447	0.0101	81.64	0.08164	0.000451	0.330111002		
	2	0.1	0.0416	0.0102	82.54	0.08254	0.000424	0.327356871	0.001377	1.914
	3	0.101	0.0422	0.0096	74.61	0.07461	0.000405	0.328751086		
Average								0.329588846		
CIII	1	0.1016	0.0428	0.012	90.03	0.09003	0.000514	0.329353598		
	2	0.1058	0.0446	0.0111	88.64	0.08864	0.000495	0.329756954	0.00021	1.066
	3	0.1033	0.0434	0.0102	82.42	0.08242	0.000443	0.329655988		
Average								0.328739653		
DIII	1	0.105	0.0442	0.0114	88.36	0.08836	0.000504	0.33056774		
	2	0.1045	0.0421	0.0121	82.65	0.08265	0.000509	0.334127867	0.002481	0.868
	3	0.103	0.0439	0.0129	97.66	0.09766	0.000566	0.329353598		
Average								0.327490746		

Samples made with varying ratios of Kaolin

Samples		L(m)	W(m)	H(m)	M(g)	M(kg)	A(m ²)	T.C (JKg ⁻¹ K ⁻¹)	ST.DEV (Wm ⁻¹ K ⁻¹)	t-value
AIV	1	0.0391	0.0441	0.0095	27.83	0.02783	0.000419	0.314159772		
	2	0.1021	0.0441	0.0107	83.51	0.08351	0.000472	0.328251291	0.00899	
	3	0.0618	0.0427	0.0105	48.95	0.04895	0.000448	0.311534338		
Average								0.317981800		
BIV	1	0.0988	0.0421	0.0105	75.27	0.07527	0.000442	0.329706461		
	2	0.0598	0.0413	0.0086	42.72	0.04272	0.000355	0.311534338	0.010391	0.6979
	3	0.0979	0.0409	0.0103	78.72	0.07872	0.000421	0.329353598		
Average								0.323531465		
CIV	1	0.0983	0.0411	0.0093	75.19	0.07519	0.000382	0.328051953		
	2	0.101	0.0426	0.0102	80.59	0.08059	0.000435	0.328901431	0.003582	0.4558
	3	0.0568	0.042	0.0107	43.03	0.04303	0.000449	0.322316376		
Average								0.326423253		
DIV	1	0.103	0.0422	0.0113	87.38	0.08738	0.000477	0.330496578		
	2	0.1066	0.0446	0.0113	87.74	0.08774	0.000504	0.328600929	0.00279	0.6152
	3	0.0883	0.0372	0.0156	81.93	0.08193	0.00058	0.325003940		
Average								0.328033815		

Samples made with varying all the mineral ratios

Samples		L(m)	W(m)	H(m)	M(g)	M(kg)	A(m ²)	T.C (JKg ⁻¹ K ⁻¹)	ST.DEV (Wm ⁻¹ K ⁻¹)	t-value
AIV	1	0.1014	0.042	0.0106	85.45	0.08545	0.000445	0.328951588		
	2	0.1024	0.0428	0.0108	78.74	0.07874	0.000462	0.328251291	0.000581	
	3	0.0833	0.0352	0.0134	74.6	0.0746	0.000472	0.329403943		
Average								0.32886894		
BIV	1	0.0788	0.0334	0.0168	80.91	0.08091	0.000561	0.323221420		
	2	0.1017	0.0408	0.0108	81.02	0.08102	0.000441	0.330161666	0.003718	0.648
	3	0.1033	0.0439	0.0101	77.13	0.07713	0.000443	0.329001766		
Average								0.327461617		
CIV	1	0.1016	0.0429	0.0079	60.75	0.06075	0.000339	0.33006036		
	2	0.1017	0.0424	0.0102	75.19	0.07519	0.000432	0.329102184	0.001107	0.689
	3	0.0865	0.0363	0.0154	81.84	0.08184	0.000559	0.327852947		
Average								0.329005163		
DIV	1	0.0994	0.042	0.0096	76.24	0.07624	0.000403	0.329202687		
	2	0.0844	0.0345	0.0156	80.98	0.08098	0.000538	0.325539071	0.006221	1.3889
	3	0.0457	0.0419	0.0118	81.83	0.08183	0.000494	0.317072781		
Average								0.323938179		

APPENDIX B

CHEMICAL COMPOSITION OF KAOLIN, FELDSPAR, BALL CLAY AND QUARTZ

COMPDS	KAOLIN (%)				BALLCLAY (%)				QUARTZ (%)				FELDSPAR (%)			
	S ₁	S ₂	S ₃	AV	S ₁	S ₂	S ₃	AV	S ₁	S ₂	S ₃	AV	S ₁	S ₂	S ₃	AV
Al₂O₃	39.6	39.7	40.1	39.80	30.15	30.13	29.88	30.05	2.02	2.00	2.01	2.01	18.40	17.00	16.83	17.4
SiO₂	54.7	56.4	52.5	54.50	63.5	63.7	63.6	63.60	91.9	91.7	91.8	91.80	77.0	77.0	79.0	78.0
TiO₂	0.17	0.20	0.19	0.19	0.59	0.61	0.48	0.56	0.12	0.17	0.12	0.14	0.50	0.20	0.20	0.30
Fe₂O₃	0.67	0.69	0.65	0.67	1.15	1.10	0.99	1.08	1.60	1.50	1.70	1.60	0.90	0.89	0.92	0.90
CaO	0.77	0.75	0.74	0.75	0.44	0.42	0.43	0.43	0.55	0.51	0.53	0.53	0.07	0.07	0.07	0.07
MgO	0.23	0.23	0.25	0.24	0.20	0.24	0.22	0.22	0.08	0.06	0.07	0.07	0.06	0.09	0.05	0.07
K₂O	1.90	1.70	1.80	1.80	2.39	2.37	2.42	2.39	2.31	2.51	2.41	2.41	0.83	0.83	0.86	0.84
Na₂O	0.89	0.90	0.88	0.89	0.67	0.70	0.64	0.67	0.60	0.58	0.50	0.56	0.90	0.87	0.93	0.90
MnO₂	0.20	0.21	0.20	0.20	0.79	0.81	0.80	0.80	0.66	0.66	0.60	0.64	0.60	0.56	0.76	0.64
P₂O₅	0.96	0.99	0.93	0.96	0.22	0.19	0.18	0.20	0.24	0.22	0.26	0.24	0.88	0.86	0.87	0.87

APPENDIX C**SPECIFICATION FOR QUICK TIME THERMAL CONDUCTIVITY METER.**

	QUICK THERMAL CONDUCTIVITY METER
Measuring Method	Hot Wire Method
Measuring Range	0.023 To 12 W/m ⁻¹ K ⁻¹
Precision	±3 Reading Value Per Reference Plate
Temperature	-10 To 200°C (Thermal Bath Is Necessary For Measurement At Different Temperature Than Room)
Measuring Time	Standard 60 Sec (Specimen Must Be In Equilibrium)
Sensor	PD-11 Box Probe Constantan Heater Wire And Chromel-Alumel Thermo Couple.
Heater Current Precision	±0.05% Of Set Up Value
Display	30 Characteristic 7 Line LCD With Back Light Display.
Minimum Sample Requirement	Approximate 100w X 50L X 20 Thick mm Or More
External out Put	RS-232C 2 Channels Thermocouple Electromotive Force 1 Chanel
Ambient Condition	Temperature: 5 To 35 Humidity : Below 85% Rh
Power Consumption	60w
Dimension	Main Unit: 300w X 145d X 175Hmm Box Probe: 100W X 50D X 100 Hmm
Weight	9kg

APPENDIX D

PERCENTAGE BY WEIGHT OF ALUMINA IN ALL THE SAMPLES

	FORMULATION I				FORMULATION II				FORMULATION III			
SAMPLES	A ₁	B ₁	C ₁	D ₁	A ₂	B ₂	C ₂	D ₂	A ₃	B ₃	C ₃	D ₃
% OF ALUMINA	14.1	18.25	22.31	26.38	25.41	23.86	22.31	20.77	20.36	21.33	22.31	23.3
	FORMULATION IV				FORMULATION V							
SAMPLES	A ₄	B ₄	C ₄	D ₄	A ₅	B ₅	C ₅	D ₅				
% OF ALUMINA	29.31	25.81	22.31	18.82	17.28	25.4	22.31	24.27				