DETERMINATION OF THERMAL DIFFUSIVITY OF FIRED CLAY BRICKS PRODUCED FROM COW PIE MIXED WITH SELECTED UGANDAN CLAYS

BY

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DECLARATION

I, Kansiime Evalyne Mary, do hereby declare that this dissertation has been designed by me and has not been submitted to any University or academic institution for the purpose of an academic award.

Sign: ……………………………………

Date: ………………………………………

APPROVAL

This is to certify that this dissertation by Kansiime Evalyne Mary was designed and written under our close supervision. We have read through it and dully approve for submission to the board of examiners and Senate for the award of a Master of Science in Physics.

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DEDICATION

I dedicate this dissertation to my son Tugume Ethan Abba Ayanda

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This study was designed to determine the thermal diffusivity of fired clay samples produced by mixing cow pie with clays from selected districts in Uganda. The focus of the study was to find out the effect of clay particle sizes and the ratio of kaolin clay, ball clay and cow pie on thermal diffusivity. The clay particle sizes considered were 0-74, 75-89, 90-149, 150-299 and 300-349 µm, the cow pie particle sizes considered were 75-149 and 150-299 µm and the clay-cow pie ratios considered were 9:7:4, 9:6:5 and 9:7:0. The samples used in the study were compacted by using a compression machine International, England at a pressure of 50 MPa and were fired in a heating chamber (CARBOLITE, GERO, HTF 1700) up to a temperature of 950 ^{0}C at different firing rates of 1.2 ^{0}C/s, 1.3 ^{0}C/s, 1.5 ^{0}C/s and 0.5 ^{0}C/s. Thermal conductivity was measured by using a QTM-machine, density was obtained from mass per unit volume and specific heat capacity was obtained by using a simple calorimeter and applying the method of mixtures.

The average values obtained for the thermal properties in the order of increasing particle sizes were as follows; for the kaolin: ball clay: cow pie ratio 9:7:4, thermal conductivity values were 0.2254, 0.2210, 0.2214, 0.2204 and 0.2195 $Wm^{-1}K^{-1}$, density values were 1.1800, 1.1535, 1.1537, 1.1433 and 1.1490 gcm^{-3}, specific heat capacity values were 1.0670, 1.0510, 0.9810, 1.0490 and 1.0100 $Jg^{-10}C^{-1}$, the average calculated thermal diffusivity values were $0.1924e^{-6}$, $0.2021e^{-6}$, $0.1883e^{-6}$, $0.2441e^{-6}$, and $0.2039e^{-6}$ m^2s^{-1}, for the kaolin: ball clay: cow pie ratio 9:6:5 thermal conductivity values were 0.2237, 0.2221, 0.2188, 0.2200 and 0.2178 $Wm^{-1}K^{-1}$, density values were 1.1866, 1.1661, 1.1945, 1.1789 and 1.2002 gcm^{-3}, specific heat capacity values were 1.0490, 1.0810, 1.0630, 1.0450 and 1.0020 $Jg^{-10}C^{-1}$, the average calculated thermal diffusivity values were $0.1919e^{-6}$, $0.2005e^{-6}$, $0.2046e^{-6}$, $0.2080e^{-6}$, and $0.2031e^{-6}$ m^2s^{-1} and for the kaolin: ball clay: cow pie ratio 9:7:0, thermal conductivity values were 0.2871, 0.2781, 0.2771, 0.2654 and 0.2654 $Wm^{-1}K^{-1}$, density values were 1.1685, 1.1578, 1.1379, 1.1450 and 1.1280 gcm^{-3}, specific heat capacity values were 1.0690, 1.0490, 1.0460, 1.0200 and 1.0510 $Jg^{-10}C^{-1}$, the average calculated thermal diffusivity values were $0.2546e^{-6}$, $0.2439e^{-6}$, $0.2427e^{-6}$, $0.2466e^{-6}$, and $0.2254e^{-6}$ m^2s^{-1}. From the results, thermal diffusivity increased with the decrease in particle sizes of kaolin and ball clay; however, it was lower for the ratio 9:6:5. Thermal diffusivity values for the control experiment were very high and this implies that cow dung was a good pore former and should be incorporated into clay bricks to improve on their thermal insulation.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

The earth is covered by four basic components; air, water, soil and plants which support and propagate life on planet earth. Water covers 71% of the earth's surface while the remaining 29% is covered by soil, air and plants. Clay is one component of soil that plays an important role in its natural and fabricated form in sustenance of human beings and other living things. For example, water is life for both plants and animals while soil provides nutrients for plants and these plants are the food for man. This implies that all the components complement each other in one way or the other.

Different types of clay such as kaolin clay, ball clay, fire clays, common clays, fullers earth and bentonite clay are widely available in Uganda. There are a number of clay deposits in Uganda where clay occurs in abundance and these are; Mutaka in Bushenyi district, Namasera in Wakiso district, Migadde in Luwero district, Kilembe in Kasese district, Mutundwe in Kampala district and Kapeka in Nakasongora district among others. These clays differ in the amount of minerals they contain, such minerals are silica, quartz, feldspar, mica and kaolinite. Kaolin clay mined from Mutaka in Bushenyi District (largest Kaolin deposit in Uganda), mainly provides a high firing strength through mullitization. It is also a material which has a characteristic which makes it easy to work with to produce useful materials of low thermal conductivity, hence low thermal diffusivity**.** Different clay types have got different properties due to the difference in particle sizes and atomic structures hence they possess different thermal diffusivity values.

The kaolin rich clay is known to show good insulating properties since it has a relatively high porosity of about 31 % compared to other types of clay. Studies about clays have been carried out especially on kaolin clay from Mutaka to make ceramic materials that can withstand high temperatures, for example, Goodwill ceramics company, uses 40-50 wt% kaolin clay from Mutaka to make a ceramic tile because it provides a high firing strength (william O, Oruru, Olupot, and Mutonyi 2021). A mixture of quartz and kaolinite structure plus other structural compositions form a back borne of refractory products. Clay bricks are among the building materials that can be used to make low-cost houses and this is because they are easy to make even by a layman but their insulating properties have to be improved. Good burnt insulating bricks that can keep the interior temperatures of homes constant can be made from clay mixed with pore formers e.g., saw dust, rice husks, cow pie (un digested green grass and grain), among others, in an appropriate ratio so as to improve on the physical characteristics of the produced bricks (Makunza, 2006). These bricks reduce on heat conduction into building during hot hours but also are able to keep houses warm during wet days since heat conduction is always in a direction of reducing temperature.

Thermal diffusivity is one of the main parameters that gives values that can make people to differentiate between different types of insulators. It is also applied in modelling and investigations of thermal state since it controls the steady state temperature-distribution in the subsurface. It gives a measure of the rate of transfer of heat by a unit volume heat capacity of a material from the hot side to the cold side. For a substance with high thermal diffusivity, heat moves rapidly through it because the substance conducts heat quickly relative to its volumetric heat capacity and this ultimately affects a range of physical process for example cooling processes. Accurate thermal diffusivity determinations are essential in transient heat transfer and also in the determination of penetration and distribution of temperature in a body. It is also important to know the thermal diffusivity in order to determine the heat storage capacity of a material and also to be able to determine the heat transfer coefficient (heat transferred per unit area per Kelvin) since it depends on thermal properties of a medium.

In Uganda in particular, traditional building materials have not changed at all in the last few decades and according to UBOS, 2010 brick walling using fired bricks is the major construction method. This, however, has led to increased rate of deforestation by 1.7 % per annum and therefore in the next decade forests could be out of existence (ILO, 2010). The housing sector in developing countries, most of the population can only afford putting up buildings using unburnt bricks or mad and wattle, the challenge of using these materials is that heat cannot easily diffuse into these houses and therefore, they are very cold inside even when the outside is warm. African countries for example, Uganda in particular, needs a moderate insulator and that is why concrete bricks are common instead of mad and wattle. Concrete blocks are made from sand-cement mixture (concrete block) but also these bricks do provide thermal insulation values that allow some transmission of heat energy from the surroundings into buildings and these also make the inhabitants uncomfortable. They also exhibit strain-softening behaviour as time goes by. This in most cases is a disadvantage to most homesteads, commercial buildings and industries (Bhatia, 2012). This disadvantage is what prompts the well to do families to purchase traditional heat regulators to keep a room cool when outside is warm and vice vasa. This, however, is very costly and cannot solve problems of the local community who have no access to electricity.

The majority of the people in rural areas and urban slums for example have very small houses with poor thermal insulation. Heat diffuses into the houses easily and cause high temperatures during the day and therefore there is need to regulate the temperatures. However, these people cannot afford to purchase heat regulators such as fans and air conditioners since they are expensive and also costly in terms of maintenance. Such a challenge can simply be overcome by using appropriate thermal insulated bricks because these bricks absorb and release heat slowly thus keeping the house cool during hot days and warm during cold days. A thin thermal insulated brick has good thermal insulation properties just like a thick wall and this is because heat takes about 6 hours to make its way through a wall 35 cm thick (Bwayo & Obwoya, 2014). This implies that heat conducted through a wall at 4 pm will reaches the inside of a house at night but the occupants will not feel that heat since the direction of heat flow at night reverses thus good thermal comfort.

The dairy and fish industries encounter challenges especially the rotting of their products during times of power black outs and end up in so much losses since most of their products are perishables if not kept at freezing temperatures. Using clay bricks of high thermal insulation properties can keep the inside temperatures of such industries very low for a long time. The improvement of the insulation of fired clay bricks for example can be achieved by use of porosity created by biomass contained in the clay structure after firing. Bio materials like saw dust and grass are often used to create the pores but also animal wastes such as cow pie can provide an alternative biomass to create such pores. Since the main economic activity carried out in western Uganda is cattle keeping the abundant cow pie in the area can easily be ground to the acceptable particle sizes to produce the pores.

The cow pie at present is majorly used by farmers to improve the physical properties of soil for example bulk density, dry density, porosity and infiltration of clay. Most often the cow pie is abandoned and washed away by water runoff into rivers and other water bodies polluting them with excess nutrients. The cow pie is also being used by some farmers to produce biogas but this gas consists of methane, carbon dioxide, and hydrogen sulphide.

Methane is a great pollutant and is a major greenhouse gas and once it escapes into the environment, it contributes to global warming. Because of this disadvantage, cow pie can be put to use in producing light house insulating bricks especially when mixed with clay of different particle sizes. Only a small fraction of cow pie is being put to use, leaving the pollution problem to still stand out.

Alternative way of recycling cow pie must, therefore, be put in place in order to overcome the challenge of pollution. One of the ways, is to use it to make thermal insulation clay bricks since it is a combustible organic matter. Such bricks form a water proof layer since they act as a sponge to absorb any water and this helps to insulate the house from entry or loss and does not smell unpleasant. The enhancement of thermal insulation of bricks using cow pie can significantly solve such challenges at a cheaper cost (Ali *et al*., 2008). Thermal insulation of clay bricks can be improved by modifying their microstructure through selection of particle sizes of clay minerals, for example, kaoline, quartz among others, to produce ceramic materials such as floor tiles and introduction of organic materials for example cow pie since it is a combustible material, this is because the brick developed contains insoluble sodium amine that reacts with the clay minerals and hence binds the brick particles together. The use of clay and cow pie to make thermal bricks is energy saving since it produces the extra energy during the firing; it is also eco-friendly and sustainable (Olokode *et al.,* 2012). The density, thickness and thermal conductivity of rammed clay mixed with cow pie make it a particularly suitable material for solar heating since the use of cow pie will enable making thin bricks that will affect thermal diffusivity in the same way just as thick clay bricks. Clay bricks of low thermal conductivity, and of durable and optimal strength can be produced by use of cow pie that burns out after firing leaving behind voids that act as heat insulation hence altering thermal diffusivity (Katale *et al*., 2013).

Although studies about use of clay to make thermal insulated bricks have been done, few studies have been done about thermal diffusivity of fired clay samples developed from clay and cow pie. For example, a study was done about the use of clay mixed with cow pie to find the strength of a brick developed and also to develop technologies that are energy saving, eco-friendly and sustainable (Olokode, 2012). This study, however, involving this local kaolin rich clay for different particle sizes with different ratios of clay-cow pie could not provide an idea of how these ratios affect low and high thermal diffusivity. Also, a study about the use of sawdust as a pore former to produce extra energy needed during firing and also to introduce in voids was conducted but it did not provide adequate information on the effect of pore sizes created. This study therefore, is about effect of different particle sizes and different ratio kaolin, ball clay and cow pie on thermal diffusivity. Cow pie will be used as a pore former so as to reduce on its use in producing biogas, since this result into production of methane gas which is an environment pollutant gas.

1.2 Statement of the problem

Uganda as a country imports heat insulators for example air conditioners, fans among others. These are very expensive to purchase and costly in terms of maintenance. The abundant clay could be utilized by mixing it with cow pie - a biomass able to produce all particle sizes of combustible material when mixed in clay unlike some of the other pore formers, for example, saw dust which causes bloating of clay (Bwayo & Obwoya, 2014). Because of this reason it was tried as a pore forming material so as to introduce voids in a fired clay body. The voids reduce thermal conductivity hence thermal diffusivity. Also, utilizing the available natural resources to make thermal insulated bricks of known thermal diffusivity saves the economy on foreign exchange.

1.3 Purpose of the study

The purpose of this study was to determine the thermal diffusivity of fired clay samples of five different particles sizes made from clay mixed with cow pie in different ratios of 9:7:4 and 9:6:5 and a control experiment using ratio of 9:7:0.

1.4 Objectives of the study

The objectives of the study were to;

i) measure the thermal conductivity of fired clay-cow pie bricks of various particle sizes and mixture ratios.

ii) determine the density of fired clay-cow pie bricks of various particle sizes and mixture ratios.

iii) find the specific heat capacity of fired clay-cow pie bricks of various particle sizes and mixture ratios.

iv) calculate the thermal diffusivity of fired clay-cow pie bricks of various particle sizes and mixture ratios.

1.5 Hypotheses of the study

The above objectives were set to establish the following null hypotheses

Ho_1: There is no difference between the values of thermal conductivity of the samples for different particle sizes.

Ho_2: There is no difference between the values of density of the samples for different particle sizes.

Ho_3: There is no difference between the values of specific heat capacity of the samples for different particle sizes.

Ho_4: There is no difference between the values of thermal diffusivity of the samples for different particle sizes.

1.6 Significance of the study

The study addressed the effect of clay-cow pie ratio on thermal diffusivity of the fabricated bricks and also compared the thermal diffusivity values of thermal insulated bricks developed from different ratios of the mixture used.

Furthermore, the result of this study gave an indication on the values of thermal diffusivity that resulted from alteration of the particle size of clay and cow pie. These values were then compared with typical results of thermal insulating materials to find out which value were close to these results. This in turn would much benefit all those in the building industry to use thermal insulation bricks to improve on thermal insulation of buildings, it would also be beneficial in Exhaust heat management by preventing heat from the exhaust from reaching the internal components for example batteries. This in the process would prompt further research on striking a balance between thermal insulation and good ventilation for example the use of heat recovery systems.

1.7 Scope of the study

The kaolin rich clay was collected from Mutaka clay deposit in Bushenyi District in western Uganda and the ball clay was collected from Ntawo clay deposit in Mukono District in the suburbs of Kampala.

The study was confined to determine thermal diffusivity of fired clay samples that were made from kaolin clay and ball clay bricks mixed with cow pie of different particle sizes in different ratios.

The independent variables were particle sizes of clay and cow pie and change in the ratio, density, specific heat capacity and thermal conductivity were moderating variables while the dependent variable was thermal diffusivity. Other factors, for example, pressing pressure of the sample were kept constant at 50 MPa and the experiment was carried out at room temperature.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction

The review of related literature has included discussion of some of the behaviours of clay as a soil type in general and how it behaves in raw and fired form, it further discusses the structure of fired clays and how the process leads to behaviour of fired clay products. The chapter also covers previous related research work carried out on thermal insulation using clay bricks, methods used to determine thermal diffusivity and it also provides information on fabrication of bricks made from clay and how combustible components in clays contribute to insulation properties of fired clay bricks. It has finally discussed the role of sizes of the particles and different ratios on insulation properties of fired bricks and how the variation of different particles mixed in different ratios affects thermal diffusivity by using an indirect method.

2.2 Nature and behaviour of clay

Clay is a soil component material and naturally exists as a fine-grained mixture of minerals composed predominantly of hydrated aluminium silicates (Pascoe, 1978). Typical clay materials have varying particle sizes ranging from 0.1 to 50 microns. A mixture of a lot of clay and a little water result in a mud that can be shaped and dried to form a relatively rigid body. This property is exploited by potters and the ceramics industry to produce plates, cups, bowls, pipes, and so on. However, environmental industries, for example, waste management industries use both these properties to manufacture homogeneous liners for containment of waste. The process by which some clay minerals swell when they take up water is reversible, clays swell because they are held by weak forces which break easily in presence of water. Swelling clay expands or contracts in response to changes in environmental factors (wet and dry conditions, temperature). Hydration and dehydration can vary the thickness of a single clay particle by almost 100 % (Crowley, 2007). Therefore, this implies that houses, offices, schools, and factories built on soils containing swelling clays may be subjected to structural damage caused by seasonal swelling of the clay portion of the soil.

Clay exists in many different compositions and forms and as such exhibits many different characteristics and behaviours. For example, ball clay among the many varieties of clays becomes plastic when wet because water conducts the weak forces that hold clay particles together (https://ceramicartsnetwork.org). It exhibits very low permeability in a wet state.

Ball clay has the ability to exchange cations while kaolin-rich clay exhibits a low ion-exchange rate and this makes it not to hold plant minerals. Most clays are fairly stable and hence very useful in the construction industry especially in making bricks and tiles. Clay provides the substrate that sustains life since it stores carbon and maintains atmospheric gases; implying that it may even have played an important role in the creation of mankind (Mukasa-Tebandeke *et al.*, 2015).

There are six general categories of clays common all over the world except that some places have got big quantities of specific types of clay than others (Bwayo & Obwoya, 2014).

Ball clays are formed from decomposed granite rocks that are washed away by water run-off and deposited in low lands by erosion agents. Ball clay is hydrated sodium calcium aluminium magnesium silicate hydroxide $(Na,Ca)0.33(Al,Mg)2(Si_4O_{10})(OH)2 \cdot nH_2O$, (Mukasa-Tebandeke *et al*., 2015). Ball clays are kaolinite rich in secondary clay with colours ranging from dark brown to black due to high organic impurities for example Silica, Tin and Titanium. The main components of ball clay are quartz (6 - 65) %, mica (10 - 25) % and kaolinite (20 - 80) %. Ball clays are high quality clays because of the low sand content which contains primary minerals for example olivine in small quantities which weathers rapidly and thus affects the rate of carbon dioxide in - take. It is used mostly in pottery, sanitary ware, floor and wall tiles making but are also added to other clays to improve their plasticity and this is because it contains fine particles. Ball clay also acts as a binder material because it's highly plastic, facilitates forming process and contributes to dry strength especially when more clay is used (Manning, 1995). In addition, it enhances the sintering process by providing a glassy phase that bonds aggregates together and this is because it contains Sodium, Potassium, and Calcium as flux (Olupot, 2010). During sintering, the atoms diffuse across the boundaries of the particles and this results into bonding particles together thus creating a single solid piece. It is an important process because it results into densification of a body and also improves strength of a body. Ball clay also contains carbonaceous matter that increases porosity after firing.

Kaolin clays are formed from chemical weathering of rocks that are found in hot and moist places. It is found in most deposits of sedimentary rocks and it is usually mixed with quartz and feldspar particles. Kaolin is a hydrous alumina-silicate mineral with a thin platelet structure. Its main constituent is kaolinite with other silicates and it offers excellent surface smoothness. There are three main minerals of kaolin and these are nacrite, dickite and kaolinite and all these have the same chemical composition ($Al_2O_3.2SiO.2H_2O$). It also consists of other six minerals and these are kaolinite, mica, quartz, feldspar, illite and montmorillonite. On a special note, kaolinite is pure clay made of 2-parts silica and 1-part alumina, it is classified as a primary clay because of its structure and location. When kaolin clay is mixed with water in a range of 20% - 30%, it becomes plastic and can easily be moulded under pressure to obtain the desired shape but if a lot of water is used in the mixing process, then a slurry is formed. On small scale application, kaolin is used in manufacture of chalk, as an insulation material in institutional and domestic stoves, it is used as a filler material in paint making (Kirabira, 2005). Kaolin makes a better choice as compared to other clays in design of naturally cooled building because it has the lowest thermal conductivity and least solar absorptivity hence a good thermal insulator as studied by (Osarenmwinda & Abel, 2014). These two studied the performance evaluation of refractory bricks produced from locally sourced clay materials in Delta state, Nigeria. In this study, it was discovered that kaolin had the best properties to be used as a good thermal insulator because it had a fair porosity of 31.44 % and a small percentage of loss of ignition, however, this study did not focus on how to improve on the insulating properties of this type of clay. In a study about physical properties of composition of kaolin, it was discovered that using kaolin clay mixed with any other type of clay affects many properties of brick samples especially the porosity. The plasticity of kaolin clay varies depending on the particle size and chemical composition. It should be noted with concern that most ceramic products in Uganda for example tiles, sanitary ware, among others are imported and this implies that only a small percentage of Uganda's clay has been put to use yet for example, Uganda's kaolins are of good quality since this type of clay presents substantial shrinkage when fired [Kirabira, (2005) and Nyakairu *et al.,* (1998)] and also it compares well with those made in foreign countries. The main impurity in Kaolin clay is Iron oxide which reduces the whiteness of kaolin (Natarajan, 2018). Therefore, if it is to be used when white in colour, it must be beneficiated first in order to remove the impurities.

Fire clays are formed from weathered sedimentary rocks that are deposited in swamps, swallow lakes, seas and other water bodies. This type of clay consists mainly of alumina silicates and contains different amounts of impurities for example, magnesia, iron oxides, lime and other alkalis. It has an average silica content ranging from 50 % to 60 %. Fire clays according to United States Environmental Protection Agency, are defined as mineral aggregates composed mainly of hydrous silicates of Aluminium with or without free silica.

Fire clays are simply normal mud with a high alumina content of which (10-15) % of it shrinks on firing and these clays withstand high temperatures of above 1500 ^{0}C and because of their high refractoriness, they are used to make fire bricks.

Common clay are clays formed after a long period of gradual chemical weathering of rocks, they basically have fined grained particles. These clays are composed mainly of silica, alumina and sometimes magnesia. This type of clay is resistant to heat since it contains so many impurities and it occurs in many places. It is plastic in nature due to its particle size and as well as its water content and therefore can be used to make clay bricks because such bricks prevent entry of heat into houses hence providing thermal comfort of the occupants.

Fuller's earth is formed from slow transformation of volcanic rocks. Fuller's earth is the type of clay that is naturally occurring with fine-grained particles. This type of clay is composed mainly of aluminium and a lot of magnesium silicates. It is a good absorber of impurities and once mixed with baking soda and silica gel, it absorbs the foul-smelling cat urine. It has a fine-grained structure and has got a high-water content hence can be used for a wide range of applications for example industrial, medicinal and cosmetology. It is also used as a bleaching agent because it was originally used to remove fat and grease from woollen clothes.

Bentonite clay is formed from volcanic ash that has settled into the ground and are sand witched between other types of rocks. It contains naturally occurring minerals for example calcium, magnesium and iron. It is the type of clay that is in form of fine ash obtained from volcanic areas. It forms a paste when mixed with water and a major type of bentonite clay known as calcium bentonite is found all over the world. When water is added to dry bentonite clay, the clay swells to a volume bigger than the original dry volume of the clay. It is for this reason that bentonite clay is used as a buffer material in a repository for spent nuclear fuel. The swelling pressure of bentonite can only be reduced by adding salt into the bentonite-water mixture. It has a high level of water absorption and this makes it to be used for a wide range of applications for example it is used to improve workability and flow of concrete and makes the finished product water-proof. In other words, it's better applied in suspensions to give a liquid or fluid a certain mechanical property of either plasticity or viscosity (Odom, 1984). There are different types of bentonite each named after the respective dominant element. These elements are potassium (K), sodium (Na), and aluminium (Al). The two main classes of bentonite clays common especially in industries are; sodium bentonite and calcium bentonite.

2.3 Clay properties and components

Water molecules are strongly attracted to clay mineral surfaces for example when a little clay is added to water, a slurry forms because the clay distributes itself evenly throughout the water. This property of clay is what is used by the paint industry to disperse pigment evenly throughout a paint. Without clay to act as a carrier, it would be very difficult to evenly mix the paint base and colour pigment. Another important property of clay minerals is the ability to exchange ions. Ions are attracted to the surface of a clay particle or taken up within the structure of these minerals. This property causes ions in solution to be attached on clay surfaces or within internal sites and, therefore, clays can be an important vehicle for transporting and widely dispersing contaminants from one area to another.

The most important components of clay are Alumina and Silica; these components improve on the refractoriness of the final product so as to withstand very high temperatures. High alumina refractory fire bricks have a very good ability of anti-acidity, anti-metal fluid corrode and anti-oxidation. Alumina is the main constituent of clay and for this reason, it acts as a cementing material in raw bricks. Brick clay is plastic due to the presence of alumina which makes the bricks to be easily moulded (Singh, 1996). Alumina content in a clay brick can also be increased by adding topaz, bauxite, kynitesillimaniye during the moulding process (Sadiki *et al*., 2014).

Ceramics are inorganic non-metallic materials formed majorly by effect of heat and hydrothermal actions at extreme pressures of the earth's crust (Pascoe, 1978). During firing, the gas pressure inside closed pores results into an increase in pore size which in turn results into increased porosity. For bricks made with clay mixed with cow pie when fired, the cow pie burns off leaving voids. These voids are filled with air which acts as an insulator and retards the rate of heat flow into a building. Increasing cow pie content in a brick material results into increased porosity hence reduced thermal conductivity. This also results into a weaker ceramic body and therefore in places where structural insulating fire bricks are required, such a brick cannot be used. Before using a ceramic body factors like fire resistance, durability, strength, thermal conductivity must be put into consideration. Also, for fired samples, bulk density, thermal sock, water absorption, porosity must also be considered. Porosity is one of the major factors that affect some of the properties of ceramic materials for example strength. Porosity is produced in a ceramic body by introducing pore formers for example sawdust, coke, rice husks and so many other materials. The typical structure of the brick is caused by the shaping process and the porosity (Fukia *et al*., 2018).

The pores in fired clay samples are formed by burning out of combustible materials such as grass, saw dust or agricultural remains. The main importance of using pore formers for example cow pie is its pozzolanic activity with the clay since this reduces the moisture content of the pore former. One of the advantages of low porosity is high strength which leads to high thermal conductivity hence high thermal diffusivity. Cow pie which is basically made up of undigested grass and grain can be used to make pore forming combustible material. Cow pie is high in organic materials and rich in nutrients. It contains about 3 % nitrogen, 2 % phosphorus, and 1 % potassium (3-2-1 NPK) (Nikki, 2019). Cow pie is used as an efficient fuel and biogas producer, this is possible because once the biogas is combusted with oxygen it produces energy. It is also used as a building material, a raw material for making paper since it contains cellulose which is a raw material for making paper and a mosquito repellent. Heniegal *et al*., (2020) says that dry cow pie fired at very high temperatures kills germs and bacteria and heals wounds and that dry cow pie can be used as a great scrub to get rid of dead skin and improve one's blood circulation. Cow pie reduces brittleness and increases workability when mixed with clay and these results into a uniform homogeneous mixture. It improves the plasticity of clay and also acts as a reinforcing agent which reduces concentrated cracks that can lead to breakage within the raw brick as investigated by Younoussa *et al.*, (2016). In this investigation, they discovered that the presence of fibres in the cow dung reduces the spreading of cracks in a brick- thus cow pie can be used as a reinforcing material and this is because it improves on water resistance in a brick. Therefore, such a brick can even be used in wet climates. The study, however, did not give the optimum amount of cow pie to be added in order to obtain the varying thermal insulating properties.

When firing brick made from clay mixed with a combustible organic matter for example cow pie, the cow pie ignites and this leads to even firing of the brick material, this in turn leads to development of high temperature gradients within the brick and finally this leads to low energy consumed. Cow pie also reduces the unit weight since clay containing soil is heavier than clay-cow pie mixture and therefore this improves thermal characteristics of a brick reinforced with cow pie. Higher amount of coarse or lesser amount of fine particles result in higher porosity level due to poor filling up of voids in between the coarse particles. This implies that particle size distribution of clay affects porosity (Meena, 2011). Insulated bricks have got either vertical or horizontal pores created when the organic matter oxidizes during the firing process, forming carbon dioxide and water vapour. **Figure 2.1** is an example of an insulated brick.

Figure 2.1: Insulated fire brick

2.4 Uses of clay

Clay products have been used in all parts of the world for processing various forms of ceramic materials since antiquity (Crowley, 2007). Clay is still used today in the ceramics industry for producing products such as white wares, bricks, roofing tiles, Sculpture, rituals, plastering and many others and this is because the clay material is ubiquitous. Ball clays are restricted to manufacturing of bricks, roofing tiles and pottery products. On a small scale, other clay types for example kaolin are used in the manufacture of chalk and as a filler in paint making. The average weight of a brick in Uganda ranges from 2.5 kg to 7.6 kg and are of dimensions length 220 mm 295 mm by 100 mm 150 mm by 60 mm 130 mm. Ceramics are used as electrical insulators because they do not form free electrons hence have a low electrical conductivity and at normal temperatures, they absorb and store energy and then release it at a slow rate hence can be used as heat insulators. In other words, ceramics are bonded together ionically and are arranged in an amorphous solid. Ceramics can be made in a traditional way where by the basic raw materials are obtained by mining the clay from clay pits, the clay is then reduced to the desired particle sizes through grinding. Additives may be added before so as to create the desired porosity. Kaolin clay is an important raw material used in ceramics because it can withstand high temperatures without melting, it has a high resistance to corrosive agents. For ceramics to withstand harsh conditions, they must be sintered, sintering means particle-to-particle bonding that takes place in a ceramic matrix when there is an increase in temperature.

2.5 Thermal insulation of clay bricks

Heat liberated from heat of combustion increases the porosity in insulating bricks and this reduces the transfer of thermal energy whenever there is a temperature gradient because the pores in the brick are filled with air so act as insulators. Generally, thermal insulation characteristics of clay bricks are affected by firing temperature, particle size of the pore former, particle size of the clay mineral and chemical composition of the clay brick. The use of organic matter has also been an on-going process because it improves on thermal insulation, reduces environmental impact, produces light weight bricks which reduces thermal load and also helps to overcome scarcity of building materials. To create high porosity in a ceramic body, some organic matter for example cow pie must be added at the time of its formation. The organic matter burns out creating voids that are filled with air which reduces the thermal conductivity leading to low thermal diffusivity of the brick. However, an increase in porosity of a thermal insulated brick degrades the mechanical strength of the brick and this can cause structure problems because gases and liquids at very high temperatures easily penetrate porous bricks. Also, when there is a temperature gradient, the hot end of a brick expands more than the cold end and this leads to mechanical stress in the body which may lead to cracking (Bhatia, 2012).

Also, the firing process volatilises organic matter and removes all the absorbed water held inside the brick leaving small micro pores and voids. For bricks that are made without paying attention to the chemical characteristics of the clay, these small micro pores hold water, this water remains in these pores by the action of capillarity and surface tension forces. This therefore, is a disadvantage since it results into sustenance of wetness in a wall which is common problem in most buildings. It is on such background that the Uganda National Bureau of Standards (UNBS) must ensure quality control of all the bricks used during construction to avoid wet walls that result into collapsing of buildings leading to a lot of destructions. It is also very important to control the rate of shrinkage during commercial production of bricks by adding in quartz to the clay-cow pie mixture. The classification temperature of insulating fire bricks is affected among others by alumina content and the firing temperature. Thermal insulation is also applied in exhaust heat management to prevent the heat produced by the engine from reaching essential parts for example batteries, sensors and starter motors. The property of thermal insulation is also applied in creating a balance between safety and performance in aerospace and automotive industries.

In hash climates, utilizing thermal insulation in the building envelope can easily reduce the building thermal load and this in turn reduces the energy consumed. The performance of the thermal insulation material is determined by its thermal conductivity which in turn also depends on porosity, moisture content and the temperature difference. Thermal conductivity is directly proportional to thermal diffusivity of a material but low thermal conductivity is essential for materials to be used as thermal insulators (Sunday et al.,2003).

Thermal insulating bricks do not transfer heat directly into houses or outside but they retain it for a long period of time. A combination of high insulation value materials and high thermal mass reduce the amount of energy needed to cool or heat a home. The transfer of heat in ceramic bodies is an important property to many people especially those in construction industry for example a furnace designer needs to first know accurate thermal conductivity values for different parts of a furnace before constructing it.

2.6 Firing of ceramics

Ceramics just like stones are tough and very strong, however, if unfired these ceramics are just soft and not durable. It is said that ceramics have been able to survive for thousands of years just because ceramics met fire. The main aim of firing a clay body is to ensure that the clay and the glaze reach their maximum level of melting. This kind of melting is not visible with human eyes, it is simply melting at molecular level. This can be achieved in two ways; bisque firing and glaze firing. Bisque firing refers to firing a clay body that is not yet glazed. It is sometimes called bisquit firing. It is done so as to turn the clay body into a “glass-like” material and must be done only if the clay body is in a dry state. The green dry body is put in a kiln, heated slowly so as to completely remove all the atmospheric water. The temperature is then gradually increased to 349 ^{0}C, so that chemically bonded water is driven out of the clay body. At a temperature of 499 ^{0}C, the clay body turns into a ceramic body. As the temperatures increase to 943 ^{0}C, the clay body has been completely sintered and it is porous to undergo the glazing process. At this point, the ceramic body should be left inside the kiln so as to undergo a slow cooling process such that the clay body does not explode due to steam build up inside the body especially if there is a rapid change in temperature.

Ceramic glazing is the second phase of the firing process that is needed especially if the ceramic material is to be used to hold liquids and also this process transforms the clay body into a rock-hard substance. The high energy dissipated especially through use of firewood leads to air pollution and this is not a one day activity because in Uganda, in particular, firing bricks in a kiln takes about 4 days (Nyakairu *et al*., 2002). The energy lost in a kiln can be reduced by using kilns with a lower volume to surface ratio (using large rectangular kilns). Also, to improve on energy efficiency, kilns should be made large with affordable recovery systems. There is a relationship between kiln sizes and energy lost during the firing-cooling process. Table 2.1 below shows the kiln sizes, brick sizes, cooling ratios and average energy wastes of different kilns.

Table 2.1: Energy loss by kilns of different dimensions, brick number and different sizes

Kiln size dimensions m	**Brick size/mm**	**Number of bricks/ x 10^3**	**Energy waste /J**
2.5x2x2	228x111x76	19234	348
3x3x3.1	290x140x90	101946	199
5x4.5x4.3	290x140x90	353524	133
6x6x4.3	290x140x90	565639	100

During firing, it is very important to control air flow for example too much air entry results into cooling down of bricks and also waste of energy while too little air flow results into poor burning of bricks.

Unlike concrete bricks, clay bricks have got excellent fire resistance characteristics since they can be heated to temperatures about 1000^0C. A brick may be fired at very high temperatures but take long to reach fire failure, that is to say a brick takes a long time to crack or to collapse when heated to very high temperatures. The use of building using fired bricks especially in schools and factories where fire outbreak is on an increase reduces losses resulting from such fires. A good thermal insulated clay brick should be fired to low temperatures in the primary stages of firing in order to minimize the shrinkage rate during the firing process. A fast-firing rate results into development of cracks due to steam build up inside the brick. Therefore, during firing, the temperatures must be increased gradually and also there is need to hold certain temperatures as to allow the clay body to form into a hard body. Once the maximum firing temperature is reached, the samples should be left inside the kiln in order to avoid rapid cooling which results into cracking of the samples.

2.7 Measurement of thermal properties of insulated fired bricks

2.7.1 Thermal conductivity

Thermal conductivity is the ability of a material to conduct heat easily through it. It states that the rate at which heat moves through a body is directly proportional to the negative of the temperature gradient and also directly proportional to the area through which heat flows. It should be noted that materials with a high value of thermal conductivity are applied in heat sinks while those with a low value are used in thermal insulators. Insulating materials have thermal conductivity values ranging from 0.023 $Wm^{-1}K^{-1}$ to 2.9 $Wm^{-1}K^{-1}$ and therefore, using kaolin rich clay from Mutaka to make clay bricks is expected to produce a thermal insulated product. The main factors that affect thermal conductivity value are density of a material, moisture of a material and ambient temperature but other factors for example chemical phase of the material, thermal anisotropy, electrical conductivity, influence of magnetic fields and isotropic purity of the crystals also affect it. Thermal conductivity increases with decrease in particle size of clay when the amount of the added pore former is constant. There are a number of possibilities to measure thermal conductivity, each of them suitable for limited range of materials and also depending on the thermal properties of the material Sumikama *et al*., 1997). Thermal conductivity is defined by the total porosity as well as pore shape and pore size distribution.

In general, there are two basic techniques of measuring thermal conductivity, the steady state and non-steady state (Based *et al.*, 2013); The steady state technique involves measurement of thermal conductivity when the material is analyzed in a complete equilibrium. This method includes Searle's bar method for good conductors and Lee's disc method for bad conductors. The disadvantage with this method is that its time consuming to attain equilibrium and also requires a very well-engineered set up for one to use it. The last technique is the non-steady state technique which involves measurement of thermal conductivity during the process of heating and the advantage of using this method is that the measurements can be made quickly (Abou-baker, 2014). This method is important because of the large number of heating and cooling problems occurring industrially. The examples of non-steady state technique that can be used to measure thermal conductivity are; the Quick Thermal Conductivity meter (QTM), Linseis Transient Hot Bridge, Transient plane source, Transient line source and the Flash method. It is difficult to mathematically analyse data obtained from measurements while using non-steady technique.

A QTM-500 in Figure 2.2 is a machine used to measure thermal conductivity of bricks since it makes it possible to measure thermal conductivity of the sample within 60 seconds by using probes containing temperature sensors.

Figure 2.2: A picture of a QTM machine 500

It consists of a heater made of Constantine wire and a chromelalumel thermocouple. The use of a heating wire is to supply heat to the sample while the thermocouple monitors the rate of heat flow. This instrument operates with a transient line source in a transient heat mode and is very effective for measuring thermal conductivity of a plane cut surface of a brick. It uses the hot wire method and is easy to use with a precision of ± 5 %. The sample block is placed in the probe box and the sensor probe is placed on the sample surface and the metre is then switched on. If the sample is not in equilibrium with the probe box, the screen displays ‘Meas Wait’. After four minutes the screen displays ‘Meas OK’. And an alarm is made, the start button is then switched on. During the measurements, a curve of temperature against time will be plotted on the screen. The curve is exponential, the angle as measured from the x-axis is greater for material with a low value of conductivity, which implies that heat moves rapidly through the body. After 60 s, the value of thermal conductivity is displayed on the screen.

The Linseis Transient Hot Bridge measures thermal conductivity of materials in different forms for example gels, pastes, liquids and solids. One plane of two halves of the sample is sufficient for the sensor and this machine measures absolute values with a wide range of temperatures -100 ^{0}C – 200 ^{0}C with a Kapton insulated sensor and with an uncertainty which is not behind that of laser flash devices. This method can also be used to measure thermal diffusivity and specific heat capacity because it gives results directly with high accuracy within a few minutes. It can also be used to measure thermal conductivity of metals and isolating materials for example; fibre glass, mineral wool, cellulose, natural fibres, polystyrene, polyisocyanurate, polyurethane, vermiculite, among others.

The Flash method measures thermal conductivity through application of a heat pulse at one end of the sample material with pre-determined dimensions and analysing the temperature change at a small distance from the point of application of the heat pulse. The material is first coated black and therefore acts as a small body. One face is struck by an intense light of known wave length and intensity and therefore, the amount of energy that strikes the surface can easily be calculated. The opposite face is in contact with the thermocouple which measures the temperature of that face. An oscilloscope therefore, plots a graph of temperature against time and thermal diffusivity can be obtained from the shape of the graph. The disadvantage with this method is that it is complicated because of the manner of the specimen. It also requires a lot of time to study the experiment and advanced mathematics models are required to analyse the results obtained.

The transient plane source method involves use of special mathematics models to determine thermal conductivity. It measures thermal conductivity values of solids, liquids, thin films, pastes among others. A proper sensor size is sandwiched between two homogeneous sample halves so as to maximize penetration. A flat sensor with a continuous double spiral is placed in between two layers of a polyamide film Kapton that is very thin and the film provides electrical insulation and mechanical stability to the sensor.

The transient line source method can be used to measure both thermal conductivity and thermal diffusivity by using an expression with Euler gamma constant. It involves plotting a graph of probe temperature against the natural logarithm of time and the slope of the graph gives the value of thermal conductivity.

In summary, the expression for thermal conductivity can be illustrated by using Figure 2.3. Consider a brick of thickness, dx and cross-sectional area, A, then Fourier's law of heat conduction can be derived as follows;

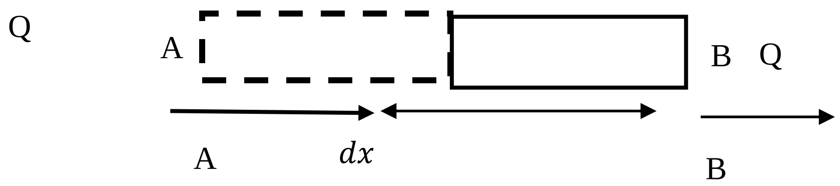

Figure 2.3: Illustration of heat conduction through a brick

T + dT and T are surface temperatures at ends A and B respectively. T + dT is greater than T, if both dT and dx are very small, then the quantity of heat that passes through the brick is proportional to the area of each surface of the brick.

$$\text{That is. } Q \propto A \qquad (2.0)$$

Also, the heat conducted is proportional to the temperature gradient in the direction of heat flow

$$Q \propto (T - (T + dT)) \qquad dx$$

$$Q \propto -\frac{dT}{dx} \qquad (2.1)$$

The quantity of heat conducted is directly proportional to the time, t of heat flow

$$Q \propto t \qquad (2.2)$$

Combining the equations (2.0), (2.1) and (2.2) we get

$$Q = -k\frac{AdT}{dx}t \qquad (2.3)$$

Equation (2.3) is Fourier's law of heat conduction which is the basic law of heat conduction. A low thermal insulating material with low conductivity for example kaolin has a low thermal conductivity and low solar absorptivity. The thermal conductivity values of moulded clay bricks fired at a high temperature range between 900 ^{0}C to 1200 ^{0}C as studied by Viruthagire, (2013) were found to be in the range of 0.0417 $Wm^{-1}K^{-1}$ to 0.1429 $Wm^{-1}K^{-1}$. The thermal conductivity of clay materials though low, depends on how the clay was prepared. The thermal conductivity values of brick samples made from clay mixed with additives like saw dust, for example, ranges between 0.2300 $Wm^{-1}K^{-1}$ to 0.4800 $Wm^{-1}K^{-1}$ as studied by (Ayugi, 2011).

Using the Lee's disk method to study thermal conductivity of clay brick samples, Mukwasibwe, (2005) obtained thermal conductivity values in the range of 0.1300 $Wm^{-1}K^{-1}$ to 0.3000 $Wm^{-1}K^{-1}$. Bwayo and Obwoya, (2014) found out that the thermal conductivity of brick samples developed from kaolin clay, ball clay mixed with saw dust was in the range of

0.2112 $Wm^{-1}K^{-1}$ to 0.2427 $Wm^{-1}K^{-1}$. Therefore, the clay type and presence pore formers do affect thermal conductivity values. The size of clay particle and pore's size do affect thermal conductivity of clay bricks as well, also, the bigger the particle size of the pore former, the lower the of thermal conductivity value.

2.7.2 Density

The mass per unit volume of a ceramic body decreases with increase in particle size of clay at fixed particle size of the pore former. This is because large particle size of clay result into less contact points that do not allow for more cohesion and lubrication. Also, similar particle size distribution of clay particles results into low density of the ceramic body due to less contact points resulting into many voids. To increase on the density of a ceramic body, multiple particles sizes should be used because smaller particles fill in the voids of large particle sizes thus high packing density (Bwayo and Obwoya, 2014). Understanding particle size distribution helps in determining the packing and fired density of the final clay body formed. If small, medium and large particles are used during the process of making a ceramic body, the interlocking qualities for, example, porosity and density increase and if a large number of coarse particles are used then the porosity increases further (Meena, 2011). Also decreasing particle sizes of clay results into decrease in specific heat capacity but an increase in thermal conductivity and thermal diffusivity.

Density varies with varying clay particle sizes but an addition of a combustible organic material decreases it. A high-density brick material limits the speed and the distance heat moves through it. Density is affected by temperature and pressure but their effect is small on liquids and solids. Increasing the pressure on a solid material leads to an increase of density of a material. But for temperature increase, it results into a decrease in density except for water at 0 ^{O}C and 4 ^{O}C. Density can be calculated by applying the equation,

$$\text{density, } \rho = \frac{mass, m}{volume, v} \qquad 2.4$$

Where by the mass, m will be obtained by using an electronic beam balance shown in Figure 2.4.

Figure 2.4: An electronic beam balance

The density of brick samples developed from kaolin clay and ball clay of the same particle sizes mixed with saw dust increased with a decrease in particle sizes from 1080 kgm^{-3} to 1258 kgm^{-3} as studied by Bwayo and Obwoya, (2014). However, with increased saw dust addition, the density decreased from 1232 kgm^{-3} to 1117 kgm^{-3}. Also, in a study by Ayugi, (2005), the density of brick samples made from kaolin clay, ball clay and saw dust, obtained was in the range of 1.67×10^3-2.18×10^3 kgm^3. This implies that small particle sizes result into dense solid body.

2.7.3 Specific heat capacity

Specific heat capacity relates to the amount of heat a material holds per unit mass due to unit temperature rise at a time. For a brick of a higher specific heat capacity, heat from the outside of the building takes long to reach the inside of a house hence good thermal insulation (Bhatia, 2012). A substance with high specific heat capacity heats up and cools down slowly while a substance with low specific heat capacity heats up and cools very quickly implying that specific heat capacity is inversely proportional to thermal diffusivity. This implies that a good brick to be used in house construction must possess high specific heat capacity because this results into significant savings in cooling and peak load reduction. In other words, this time lag effect can save energy and money (Faria Jr. *et al.*, 2011). To determine the specific heat capacity, the equilibrium temperature of the mixture is measured and taking into account that a small unknown amount of heat transfer occurs through the boundaries of the mixture system. Specific heat capacity can be determined using method of mixtures and applying the second law of thermodynamics as shown in equation (2.4) (Sandra, 2008). For a single component system, the adiabatic assumption is never achieved in real life but simply formulate $Q=mc(\Theta_2-\Theta_1)$ to calculate it, but for a two-component system the second law is used where by energy lost by one component minus energy gained by another component is zero. In both cases, however, the general principle of all calorimeters for example that in Figure 2.5 is to ensure that there is no heat loss to the surroundings.

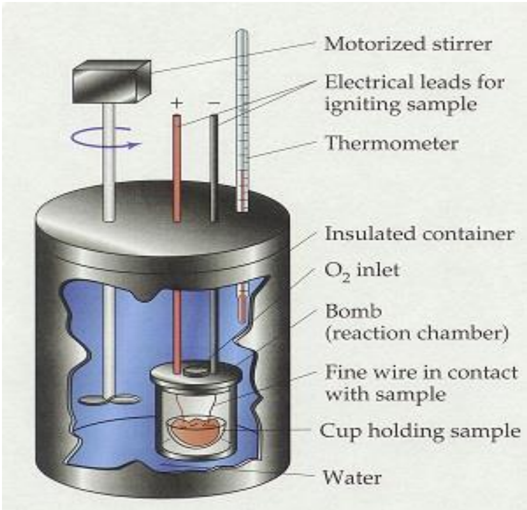

Figure 2.5: An ordinary calorimeter

Heat capacity together with thermal conductivity, density and thermal diffusivity are major parameters used in calculating the energy consumed in a building and hence determine energy efficiency. From the second law of thermal dynamics,
Heat lost by a brick sample is equal to heat gained by a calorimeter plus heat gained by water, assuming no heat is lost to the surroundings.

$$m_r c_r (\theta_3 - \theta_2) = m_c c_c (\theta_2 - \theta_1) + m_w c_w (\theta_2 - \theta_1) \qquad (2.5)$$

where m_r mass of the brick, c_r specific heat capacity to be determined, m_c mass of the calorimeter, c_c specific heat capacity of the calorimeter, m_w mass of water, c_w specific heat capacity of water, θ_3 temperature of the heated brick sample, θ_2 equilibrium temperature of the mixture and θ_1 initial temperature of the calorimeter and water.

Theoretically, if energy, Q is a function of temperature, T, volume, V, and number of particles in a system, N, then

$$Q = Q(T, V, N) \qquad (2.6)$$

By Taylor's expansion equation (2.5) becomes

$$Q(T + \Delta T, V, N) = Q(T, V, N) + \Delta T \left(\frac{\delta Q}{\delta T}\right) + \varphi(\Delta T^2) \qquad (2.7)$$

As the brick is heated by some amount of heat, the energy will change and therefore, equation (2.6) turns into

$$Q\ (T + \Delta T, V, N) - Q\ (T, V, N) = \Delta Q$$

$$\Delta Q = \Delta T\ \left(\frac{\delta Q}{\delta T}\right) + \omega\ (\Delta T^2) \qquad (2.8)$$

If the temperature change is small then, $(\Delta T^2) = 0$ and equation (2.8) becomes

$$\Delta Q = \Delta T\ \left(\frac{\delta Q}{\delta T}\right) \qquad (2.9)$$

The derivative in equation (2.9) is heat capacity

$$\Delta Q = C_V\ \Delta T \qquad (2.10)$$

In terms of specific heat capacity, $C_V = \left(\frac{\delta Q}{\delta T}\right)$ and equation (2.10) becomes

$$m\ C_{v} = \left(\frac{\delta Q}{\delta T}\right), \qquad (2.11)$$

$$\text{where, } C_{v} = \frac{1}{m}\left(\frac{\delta Q}{\delta T}\right)$$

.

Specific heat capacity can also be measured by using laser flash method, here the temperature rise of the sample is compared to the temperature rise of the reference sample of known specific heat tested under the same conditions.

The Dual-Needle Heat-Pulse can be used to measure specific heat capacity, thermal diffusivity and thermal conductivity simultaneously. It measures thermal conductivity of solid particles for example soil. It consists of a line heat source and a thermal couple whose temperature response can be used to determine thermal diffusivity and thermal conductivity hence calculate volumetric heat capacity. The Dual-Needle heat-Pulse compares well with a capacitive sensor since they both have an accuracy of ± 3 %.

Differential scanning calorimeter is the most appropriate instrument used to measure specific heat capacity because it is easy to use and it’s operated within a short period of time. It is always operated at a constant pressure and therefore heat flow is the same as the enthalpy change. During its operation, the scanner scans the sample at the desired rate over a given period of time and the calorimeter produces a thermogram depending on heat gain or loss and the amount of heat energy required to maintain the temperature is recorded with an accuracy of ± 2 %. The specific heat capacity of brick samples decreased with a decrease in particle sizes of clay and saw dust from 1002 $Jkg^{-1}K^{-1}$ to 712 $Jkg^{-1}K^{-1}$ as studied by Bwayo and Obwoya, (2014) while in a study by Ayugi, 2011, the specific heat capacity values were in a range of 677 $Jkg^{-1}K^{-1}$ - 942 $Jkg^{-1}K^{-1}$. This shows that small particle sizes of clay retain more heat as compared to big particle sizes.

2.7.4 Thermal diffusivity

The calculated thermal diffusivity value of a material depends on density, thermal conductivity and specific heat capacity of the material. For example, the density of fired brick is affected among other factors by the firing temperature and the pore former material used. For a range of temperature 573 ^{0}C to 700 ^{0}C, thermal diffusivity increases with increase in temperature. Higher temperatures and large pore formers used in production of a burnt brick leads to a reduction of bulk density of a brick material. Higher densities of brick materials as a result of packed atoms coupled with low temperatures and small size pore formers lead to lower thermal diffusivity and this is because of a low rate of heat passing through a material during temperature changes. The physical implication of thermal diffusivity is associated with the penetration of heat into a material medium during the rate of change of temperature with time. For a material having a high value of thermal diffusivity less time is required to remove such heat because the faster the penetration, the faster the removal.

Thermal diffusivity also depends on particle size distribution, mineralogical composition, nature of organic matter burnt and firing temperature. It is one of the most important parameters needed when calculating the energy consumption and energy efficiency of any building structure and this is because it influences the movement and behaviour of heat.

It is very important to improve on the already existing methods for determining the characteristics of materials. One of the disadvantages of some experiments used to measure thermal diffusivity include thermal resistance between the specimen and the source of heat but to avoid this, a flash method has been improved to overcome it. Also, because of the few challenges associated with the flash method for example the experimental set up being time consuming to analyse the experiment, a Solid Pulsed Infrared Thermograph (ITR) was developed to easily determine thermal diffusivity of a solid material. It involves stimulation of the surface of a material by a heat pulse and the response of the material is recorded as a distribution of time revolution of the solid surface. This time revolution of the surface contains thermal diffusivity information. The theory about thermal diffusivity determination depends on heat conduction equation for a plate of finite thickness and one end of a plate's surface is heated by a heat pulse but if the plate is of an infinite surface (surface of a plate is large compared to the region of interest), then for such a surface several assumptions as listed below hold;

The surface of the material before and after heating should be exothermal.

Heat conducted from the solid by conduction and convection should be neglected.

The value of thermal diffusivity of steel obtained by using IRT is close to the theoretical value and only differs by 0.5%. The advantages of using IRT include; it's very easy to interpret results, the experiment is easy to set up, the methodology used is very simple, little time is needed to take readings and it is a contactless method but this method involves high cost of thermographic systems and the surface of the specimen must be covered with a high emissivity substance.

Thermal diffusivity can therefore, be determined by an indirect method which requires measurement of thermal conductivity, density and specific heat capacity at constant pressure or setting the initial temperature distribution and boundary conditions. For fluids, it's very difficult to mathematically model thermal diffusivity because they are affected by convection that results from movement of fluids due to the heating process.

$$\text{Thermal diffusivity, D} = \frac{thermal\ conductivity, k}{density, \rho\ X\ specific\ heat\ capacity, C} \quad (2.12)$$

A simpler representation can be formed.

$$D = k/(p\ c) \quad (2.13)$$

Where D is thermal diffusivity and it quantifies the rate at which temperature concavity is "smoothed out, *k* is the thermal conductivity, *p* is the density, and *c* is the specific heat capacity at constant pressure. *pc* is often referred to as the volumetric heat capacity.

If conduction is to take place in three dimensions, then

$$\frac{\delta T}{\delta t} = D\left(\frac{\delta^2 T}{\delta x^2} + \frac{\delta^2 T}{\delta y^2} + \frac{\delta^2 T}{\delta z^2}\right) \quad (2.14)$$

For a one-dimensional model, the differential equation for conduction is of the form

$$\frac{\delta T}{\delta t} = D\left(\frac{\delta^2 T}{\delta z^2}\right) + \frac{q}{\rho\ c} \quad (2.15)$$

where D is thermal diffusivity of the tested material, ρ is the mass density, c is the specific heat capacity, and q is a function of heat sources associated with surface density Q which passes through the specimen during its heat pulse stimulation.

For measurement of thermal diffusivity directly, the following methods already discussed under thermal conductivity can be used; the Linseis transient hot bridge method or transient line source method and flash method. The disadvantage with the flash method is that there are thermal leakages through thermocouple wires.

Thermal insulation is determined by thermal diffusivity because it determines the most suitable material to use, insulation requires a low thermal diffusivity value because such a value allows less amount of heat to pass it at any time. But if you are designing a heat sink which is a material that carries heat from the appliance, then a high value of thermal diffusivity will be required because it results into quick transfer of heat. Many industries rely on thermal diffusivity to determine the most suitable materials to optimize efficient heat flow. Insulation is an example of a material that requires a low thermal diffusivity so that a minimal amount of heat is passing through it at any one time. It implies that if there is slow heat transfer, then area accepting the heat would heat up before it transfers the heat accumulated and therefore no heat flow will be permitted.

The coefficient of thermal conductivity of brick samples made from kaolin clay and ball clay of the same particle sizes mixed with saw dust, increased with decrease in particle sizes of clay from 1.58×10^{-7} $Wm^{-1}K^{-1}$ to 2.46×10^{-7} $Wm^{-1}K^{-1}$ as studied by Bwayo and Obwoya (2014). This value lies in the range of the acceptable low values of thermal diffusivity

$(1.1\text{-}3.0)\, e^{-7}$ m^2s^{-1}.

CHAPTER THREE: METHODOLOGY OF THE STUDY

3.1 Introduction

This study was designed to investigate thermal diffusivity of fired clay samples produced by mixing clay types from two local clay deposit sites of Mutaka-Kijubwe Parish in Bushenyi District which is rich in kaolin and from Ntawo in Mukono District rich ball clay. The clays were mixed with cow pie from Bushenyi agricultural farms to produce the samples for investigation. The cow pie was used as a pore former because it is in abundance and can easily be ground to acceptable size. It is combustible in dry form and has a potential to change the thermal structure of the bricks of which is a product. The methods used were to measure density, specific heat capacity, thermal conductivity hence calculate the thermal diffusivity of the brick samples developed by using two different ratios of clay–cow pie mixture and different particle sizes of clay and of cow dung with a control experiment where only clay and one ratio were used.

3.2 Design of the study

The study was designed to come up with calculated values of thermal diffusivity of clay-cow pie material and find out if indeed cow pie affected it. This was done in three parts in order to determine thermal conductivity, density, specific heat capacity and finally calculate thermal diffusivity of fired clay samples. In the first part, two particle sizes of cow pie that resulted into low and high thermal conductivity values from earlier studies were used with a range of five particle sizes of kaolin and ball clay. The ratio of kaolin clay: ball clay: cow pie was 9:7:4, it was then varied to 9:6:5 in the second part to obtain a total of 50 samples. In the third part, a control experiment was carried out using only kaolin clay and ball clay of the same particle sizes and clay-cow pie ratio of 9:7:0 to make 25 samples. A total of 75 samples were made. The ratio value 9:7:4 kaolin, ball clay and cow pie used was adapted from (Bwayo & Obwoya, 2014). The final results gave a descriptive value for density, thermal conductivity, specific heat capacity and hence thermal diffusivity for the different particle sizes of clay and particle sizes of cow pie mixed in different ratios. This gave a significant relation between variation of the particle sizes mixed in different ratios and density, specific heat capacity, thermal conductivity and thermal diffusivity in terms of correlations as were plotted on x and y axes respectively.

3.3 Sampling and sample preparation

The kaolin rich-clay of about 80 kg was procured from Mutaka clay pit in Bushenyi District in Western Uganda. The clay from Mutaka clay pits contain 36 % of Alumina (Kirabira, 2005). Ball clay of about 80 kg was obtained from Ntawo in Mukono District. These clays were kept in polythene bags in an enclosed room. Dry cow pie of about 10 kg and of not more than two weeks old was also obtained from farms in Bushenyi District. The cow pie was also stored in polythene bags

3.3.1 Preparation of clay material

The kaolin rich clay and ball clay were separately soaked in 20 litres of water for a week so as to create a paste and also to allow easy removal of floating roots, grass and leaves by scooping them. The clay pastes were separately stored for a day in plastic containers so as to enable the stones settle at the bottom by the action of gravity. The suspended clays were then decanted carefully into Plasters of Paris containers. The clays were kept for 3 days so that all the water was sucked out. Clean clays were then thinly spread on a flat surface for a week and left in open air in an enclosed room for faster drying.

The dry kaolin clay was then milled in a laboratory ball mill (Retch, PM 100, German) for 6 hours to break large particles into small particles and sieved using a mechanical test sieve shaker (Retch,AS 200, German) shown in Figure 3.1.

Figure 3.1: A mechanical sieve shaker

The kaolin rich clay was successively sieved to obtain particles of sizes in the range of 0-74µm, 75-89 µm, 90-149 µm ,150-299 µm and 300-349 µm as labeled C1, C2, C3, C4 and C5 respectively. These samples were kept separately in plastic polythene bags so as to keep them free from absorbing moisture. At least 5 extra samples of each particle size of kaolin clay were also prepared for the control experiment. The prepared kaolin samples were tabulated as shown in Table 3.1.

Table 3.1: Amounts of kaolin clay samples

Label	**Clay size/µm**	**Amount in part 1/g**	**Amount in part 2 /g**	**Amount in control experiment/g**
C1	0-74	90	90	90
C2	75-89	90	90	90
C3	90-149	90	90	90
C4	150-299	90	90	90
C5	300-349	90	90	90

The dry ball clay was milled for 8 hours to break large particles into small particles and successively sieved in a mechanical test sieve shaker to obtain particle sizes in the range of 0-74 µm, 75-89 µm, 90-149 µm, 150-299 µm and 300-349 µm labeled B similar to kaolin-clay samples table in Table 3.1 above. In this case 70 g of each particle sizes were separately kept in plastic bags and at least 5 samples of each of the particle sizes were kept for the control experiment.

3.3.2 Preparation of cow pie material

The dry cow pie was also milled for 7 hours to obtain small particle sizes and sieved in a mechanical test sieve to obtain two different desired cow pie particle sizes labelled P1and P2. These samples were kept separately in plastic polythene bags to prevent them from absorbing moisture. The cow pie particle sizes of 75-149 µm were labelled P1 and cow pie particle sizes of 150-299 µm were labelled P2 as shown in Table 3.2.

Table 3.2: Amount of Cow pie of two particle sizes

Label	**Cow pie size/µm**	**Amount/ g**	
		1st ratio	**2nd ratio**
P1	75-149	40	50
P2	150-299	40	50

3.3.3: Preparation of different clay-cow pie mixture ratios

The kaolin rich clay, ball clay and cow pie were mixed to produce three sets of ratios of kaolin: ball clay: cow pie ratios of 9:7:4, 9:6:5, and of 9:7:0 without cow pie. The first ratio of kaolin, ball clay and cow pie ratio of 9:7:4 was produced by mixing 90 g of kaolin rich clay with, 70 g of ball clay and 40 g of cow pie. The second ratio of 9:6:5 was produced by mixing of 90 g, kaolin rich clay with 60 g of ball clay and 50 g of cow pie. The last set was obtained by mixing 90 g kaolin rich clay with 70 g of ball clay alone. The amounts were measured by an electronic balance, the heaps of samples of each particle size were kept separately.

The first set of formulation was to obtain samples of clays-cow pie mixture ratio of 9:7:4 was achieved by mixing 20 g of 75-149 µm and 20 g of 150-299 µm of cow pie size particles to various particle sizes of kaolin and ball clay as indicated in Table 3.3.

Table 3.3: Mixture formulation for samples made from 9:7:4 clay-cow pie ratio

Kaolin and ball particle size/µm	**Amount of kaolin/g**	**Amount of ball clay/g**	**Amount of cow pie/g**	**Label**
0-74	90	70	40	A1
75-89	90	70	40	A2
90-149	90	70	40	A3
150-299	90	70	40	A4
300-349	90	70	40	A5

The second set of formulation was to obtain samples of clays-cow pie mixture ratio of 9:6:5 and was achieved by mixing 25 g of 75-149 µm and 25 g of 150-299 µm of cow pie size particles to various particle sizes of kaolin and ball clay. Uniform distribution of the particle sizes, was done by stirring the mixture which also involved shaking of the samples several times during the process of mixing.

The formulations were recorded as indicated in Table 3.4.

Table 3.4: Mixture formulation of samples made from 9:6:5 clay-cow pie ratio

Kaolin and ball particle size/µm	**Amount of kaolin/g**	**Amount of ball clay/g**	**Amount of cow pie/g**	**Label**
0-74	90	60	50	D1
75-89	90	60	50	D2
90-149	90	60	50	D3
150-299	90	60	50	D4
300-349	90	60	50	D5

The third set of formulation was to obtain samples of clays-cow pie mixture ratio of 9:7:0 and was achieved by mixing kaolin and ball clay only. The different clay particle sizes were mixed as shown in Table 3.5.

Table 3.5: Mixture formulation of samples made from 9:7:0 kaolin: ball clay ratio

Particle sizes of Kaolin and ball clay/ µm	**Amount of kaolin/g**	**Amount of ball clay/g**	**Amount of cow pie/g**	**Sample label**
0-74	90	70	0	E1
75-89	90	70	0	E2
90-149	90	70	0	E3
150-299	90	70	0	E4
300-349	90	70	0	E5

3.3.4 Production of the samples

A mould was fabricated from steel metals with internal dimensions of 10 cm x 5 cm x2 cm as shown in Figure 3.2.

Figure 3.2: A steel mould

A total of 75 samples of bricks of different batch numbers (at least 5 samples of each A1 to A5, at least 5 samples of each D1 to D5 and at least 5 samples of each E1 to E5 were produced using the mould by dry pressing the formulations using a compression machine (ELE International, England) in Figure 3.3.

Figure 3.3: A compression machine (ELE International, England)

A high pressure of 50 MPa and maintained for 5 minutes was applied during the production of samples in order to form a uniform green body for easy handling during processing of the samples. This made the pressure of the bricks to be stable hence avoiding any cracking especially during the firing process. The green samples were wrapped in new papers and kept at room temperature ready for transportation to the firing place.

Firing of refractory bricks was done in 4 stages to avoid development of stress on the samples. In the first stage of firing, the samples were fired in an electric heating chamber (CARBOLITE, GERO, HTF 1700, German) at a firing rate of 1.2 ^{0}C/s until a temperature of 100 ^{0}C was reached. The kiln was then programmed to hold this temperature for 30 minutes to allow easy distribution of heat throughout the body. The samples were again fired at the firing rate of 1.3 ^{0}C/s until a temperature of 300 ^{0}C was reached. The samples were then left inside the chamber for 30 minutes. In the third stage, the samples were fired at a firing rate of 1.5 ^{0}C/s until a temperature of 600 ^{0}C was reached. This temperature was held for 1 hour. Finally, the samples were fired at a firing rate of 0.5 ^{0}C/s until the temperature of 950 ^{0}C was attained, the samples were then left in the chamber for 20 hours to cool naturally to avoid any development of stress that might lead to cracking. The heating was done in this way because pore water dries out first but water of crystallization requires higher temperatures in order to completely dry. During the firing process, the bottom and top samples inside the heating chamber developed cracks on their edges and so were re-shaped after firing.

3.4 Measurement of thermal parameters of clay samples

There are several parameters that were determined before calculating thermal diffusivity and these are discussed below.

3.4.1 Measurement of thermal conductivity of fired clay samples

The QTM machine (QTM-500, PD-11) was used to measure the thermal conductivity of the samples. Each sample was placed in the probe box and the sensor probe was placed on top of the sample and the heat source was then switched on. With the sample inside the probe box, when it was not in equilibrium with the probe box, the screen would display ‘Meas wait’. After four minutes the screen displayed ‘Meas OK’. And an alarm was made, the start button was then switched on. During the measurements, a curve of temperature against time was plotted on the screen. The curve was exponential, the angle was measured from the x-axis and it was greater for material with a low value of conductivity, which implied that heat moved rapidly throughout the body. After 60 s, the average value of thermal conductivity was displayed on the screen.

The first set of average thermal conductivity values were obtained and recorded in Table 3.6.

Table 3.6: Average Thermal conductivity values of Brick Samples for 9:7:4 clay-cow pie ratio

Sample	**k (W m^{-1} K^{-1})**
A1	0.2254
A2	0.2221
A3	0.2214
A4	0.2204
A5	0.2195

The second set was obtained for the ratio of 9:6:5 and the values obtained were recorded in Table 3.7.

Table 3.7: Average thermal conductivity values of brick Samples for 9:6:5 clay-cow pie ratio

Sample	**k (W m^{-1} K^{-1})**
D1	0.2237
D2	0.2221
D3	0.2188
D4	0.2200
D4	0.2178

The results in Table 3.8 were for the control experiment made from a ratio of 9:7:0 kaolin: ball clay and cow pie.

Table 3.8: Average thermal conductivity values of brick samples for 9:7:0 kaolin: ball clay ratio

Sample	**k (W m^{-1} K^{-1})**
E1	0.2871
E2	0.2781
E3	0.2771
E4	0.2654
E5	0.2514

Table 3.8: Average thermal conductivity values of brick samples for 9:7:0 kaolin: ball clay ratio

3.4.2 Determination of density of fired clay samples

The mass of the fired bricks was obtained by using a digital electronic balance (NHBCK, T02KA0). For each of the 5 samples made for a combination of clay and cow pie, mass was measured and the average value was used in determining the average density. For measurement of volume, the dimensions of length, width and height were measured 3 times so as to reduce on the error, the average values for each particle size were also used. With volume, v = length x width x height), the density was calculated using equation (2.4). The results obtained for two sets were from using at least 5 clay size particles and two cow pie size particles with the ratio varied from 9:7:4 to 9:6:5 while the last part was obtained by using at least 5 clay size particles only with no cow pie and this acted as the control experiment.

The results in Table 3.9 were for 5 samples made from varying clay size particles for the clay-cow pie ratio 9:7:4.

Table 3.9: Average density values of Samples for 9:7:4 clay-cow pie ratio

Sample	**Particle size (μm)**	ρ **(g cm^{-3})**
A1	0-74	1.1830
A2	75-89	1.1535
A3	90-149	1.1537
A4	150-299	1.1433
A5	300-349	1.1490

The results in Table 3.10 were for the ratio of 9:6:5 kaolin clay, ball clay and cow pie respectively.

Table 3.10: Average density values of Samples for 9:6:5 clay-cow pie ratio

Sample	**Particle size (μm)**	ρ **(g cm^{-3})**
D1	0-74	1.1866
D2	75-89	1.1661
D3	90-149	1.1945
D4	150-299	1.1789
D5	300-349	1.2002

The results in Table 3.11 were for samples made from the ratio of 9:7:0 kaolin: ball clay only as the control experiment.

Table 3.11: Average density values of samples for 9:7:0 kaolin clay-ball clay ratio

Sample	**Particle size (μm)**	ρ **(g cm^{-3})**
E1	0-74	1.1685
E2	75-89	1.1578
E3	90-149	1.1379
E4	150-299	1.1450
E5	300-349	

3.4.3: Measurement of specific heat capacity of fired clay samples

The specific heat capacity of re-shaped samples of each particle size was obtained by the method of mixtures, where by the equilibrium temperature of the mixture was first obtained and recorded.

The specimens were heated one at a time in a heating mantle (FINETECH) to a temperature of 190 ^{0}C for 1 hour to ensure that the specimen and the mantle are at the same temperature. Each heated specimen was then quickly transferred into a calorimeter containing water at a temperature of 27 ^{0}C. The calorimeter was covered to minimize heat losses to the surroundings. The temperature of the mixture was determined after every 20 s until both the specimen and water attained the equilibrium temperature. The equilibrium temperature was then read from the thermometer and recorded. Specific heat capacity was obtained by applying the second law of thermal dynamics and using the equilibrium temperature of each brick sample, each average specific heat capacity value was calculated by using equation (2.4).

The first average specific heat capacity results were obtained for the ratio 9:7:4 and tabulated in Tables 3.12.

The results in Table 3.12 were for the ratio 9:7:4 kaolin clay: ball clay: cow pie

Table 3.12: Average specific heat capacity values of brick samples for 9:7:4 clay-cow pie ratio

Sample	**c (J $g^{-1 0}C^{-1}$)**
A1	1.0670
A2	1.0510
A3	0.9810
A4	1.0490
A5	1.0100

The results in Table 3.13 were for the ratio 9:6:5 kaolin clay: ball clay: cow pie.

Table 3.13: Average specific heat capacity values of brick samples for 9:6:5 clay-cow pie ratio

Sample	**c (J $g^{-1 0}C^{-1}$)**
D1	1.0490
D2	1.0810
D3	1.0630
D4	1.0450
D5	1.0020

The results in Table 3.14 were for the control experiment made by using the ratio 9:7:0.

Table 3.14: Average specific heat capacity values of brick samples for 9:7:0 kaolin: ball clay ratio

Sample	**c (J g$^{-1 0}$C^{-1})**
E1	1.0690
E2	1.0490
E3	1.0460
E4	1.0200
E5	1.0510

3.4.4 Calculation of thermal diffusivity

Thermal diffusivity was therefore, calculated by an indirect method of applying the formula in equation (2.11). The results were obtained by using average values of density, specific heat capacity and thermal conductivity of values tabulated in Tables 3.6 to 3.14.

The calculated thermal diffusivity values for the clay-cow pie ratio 9:7:4 were tabulated in Tables 3.15.

The results in Table 3.15 were for samples made from 9:7:4 kaolin: ball clay: cow pie.

Table 3.15: Average thermal diffusivity values of brick samples for 9:7:4 clay-cow pie ratio

Sample	**Diffusivity x$(e)^{-6}$(m^2 s^{-1})**
A1	0.1924
A2	0.2021
A3	0.1883
A4	0.2441
A5	0.2039

The results in Table 3.16 were for samples made from the ratio 9:6:5 kaolin: ball clay: cow pie.

Table 3.16: Average thermal diffusivity of brick samples for 9:6:5 clay-cow pie ratio

Sample	**Diffusivity x $(e)^{-6}$(m^2 s^{-1})**
D1	0.1919
D2	0.2005
D3	0.2046
D4	0.2080
D5	0.2031

The results in Table 3.17 were for the control experiment for samples made from 9:7:0 kaolin: ball clay ratio.

Table 3.17: Average thermal diffusivity values of brick samples for 9:7:0 kaolin: ball clay ratio

Sample	**Diffusivity x $(e)^{-6}$(m^2 s^{-1})**
E1	0.2546
E2	0.2439
E3	0.2427
E4	0.2466
E5	0.2254

CHAPTER FOUR: RESULTS AND DISCUSSION OF THE STUDY

4.1 Introduction

This study was designed to determine the thermal diffusivity of fired local clay samples produced from a mixture of different particle sizes of kaolin rich clay, ball clay and cow pie of different ratios. The determination of thermal diffusivity required the measurement of the thermal conductivity, determination of the density and specific heat capacity of the samples for five different clay particle sizes and three different ratios of composite materials used to produce the samples. The study led to obtaining the thermal conductivity, density, specific heat capacity and finally the thermal diffusivity of fired samples produced form kaolin rich, ball clay and cow pie of different particle sizes.

The study consequently led to testing the null hypotheses stated in section 1.5 that for each of the composite ratios, the aforesaid parameters were not affected by particle sizes of the kaolin, ball clay and cow pie. The study further led to testing the null hypothesis that for each of the particle sizes the parameters were not affected by the composite ratios.

The analysis of data involved using the mean values of dimensions of length, width and height to get the average values for volume, *v*. These were used together with the average values of mass for each sample so as to obtain the average density. Also, average values of thermal conductivity and specific heat capacity were obtained and used in calculating the average values of thermal diffusivity.

The major data analysis was done using a spread sheet. The spread sheet delt with finding the mean, standard deviation and error of the mean. The average values of thermal conductivity, density, specific heat capacity and thermal diffusivity were used to draw a bar graph showing the typical case for variation of each against clay particle sizes for two selected cow pie particle sizes.

In order to determine if there existed any statistically significant difference between mean values of thermal conductivity, density, specific heat capacity and thermal diffusivity for different particle sizes, the F-value were determined for each of the clay-cow pie ratio in response to the null hypothesis that were set in the objectives. The calculated F-values were compared to the critical F-values for the level of significance, $\alpha = 0.050$ and $\alpha = 0.010$ obtained from the F-distribution Table for the degree of freedom of 4 (numerator value) and degree of freedom 20 (denominator) that were used to read F-values from F-distribution chart (Prem, 2010). The F-value for $F_{0.010} = 4.43$, $F_{0.050} = 2.87$ standing for the levels of significance of α = 0.010 and α = 0.050 respectively. For cases where the calculated F-value was less than the critical F-value, then, the null hypothesis was upheld and for the cases where the calculated F-value was less than the critical value, the null hypothesis was rejected. Also, where the hypothesis was accepted at one level of significance but rejected at the other or both, a p- value was calculated using a p-value calculator. (https://www.danielsoper.com/statcalc/calculator.aspx?id=7). For p- value greater than the level of significance, then the hypothesis was accepted while for p- value less than the level of significance, the hypothesis was rejected.

4.2 Thermal conductivity of the samples

The first objective of this study was to obtain thermal conductivity values of the samples produced from the three clay-cow pie ratios of five different particle sizes.

4.2.1 Thermal conductivity for mixture ratio of 9:7:4

The first result was to find the thermal conductivity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4. The thermal conductivity of each of the samples of clay particle sizes of 0-74 µm labelled A1, 75-89 µm labelled A2, 90-149 µm labelled A3, 150-299 µm labelled A4 and 300-349 µm labelled A5 were obtained as shown in Table 4.1.

Table 4.1: Average thermal conductivity, standard deviation and maximum error estimate for the ratio 9:7:4

Particle Sizes	**A1**	**A2**	**A3**	**A4**	**A5**
Conductivity (W m^{-1} K^{-1})	0.2250	0.2220	0.2210	0.2200	0.2190
STDV/ (W m^{-1} K^{-1})	0.0008	0.0039	0.0039	0.0039	0.0045
Max Error ($Wm^{-1}K^{-1}$) α=0.01	0.0017	0.0081	0.0080	0.0081	0.0092
α=0.05	0.0010	0.0049	0.0048	0.0049	0.0056

To compare the thermal conductivities for the different particle sizes, a bar chart of the conductivity against particle sizes was drawn as shown in Figure 4.1.

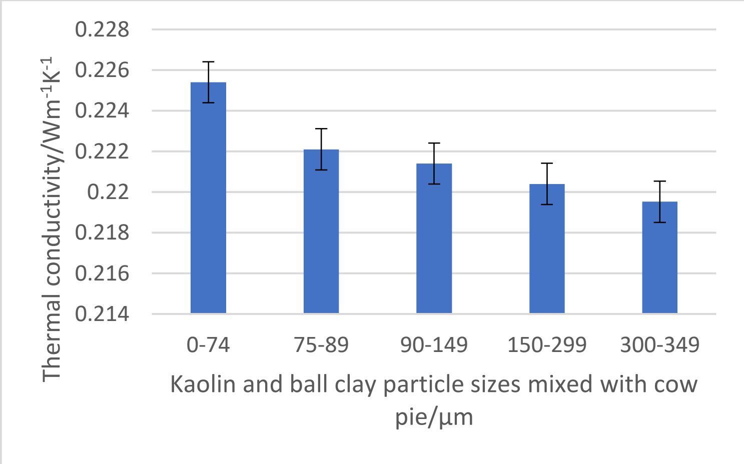

Figure 4.1: A bar chart of thermal conductivity against particle size of kaolin, ball clay mixed with cow pie in the ratio 9:7:4

The bar chart in Figure 4.1 shows that thermal conductivity of the samples for this mixture ratio of 9:7:4 increased from 0.2190 ± 0.0092 W m^{-1} K^{-1} to 0.2250 ± 0.0017 W m^{-1} K^{-1} for the levels of significance α=0.01 and from 0.2190 ± 0.0056 W m^{-1} K^{-1} to 0.2250 ± 0.0010 W m^{-1} K^{-1} for the levels of significance α=0.05 respectively with decrease in particle sizes of clays.

To test if the differences of the thermal conductivity for the different particle sizes were statistically significant, the F- value was determined for the five different mean thermal conductivities at levels of significance α=0.01 and α=0.05 as shown in Table 4.2.

Table 4.2: F-ratio calculated values and p-value for thermal conductivity for the ratio 9:7:4

F- value calculated	**F-critical value α=0.01**	**F-critical value at α=0.05**	**p-value at 0.01**	**p-value at 0.05**
1.9300	4.4300	2.8700	0.0100	0.0498

From Table 4.2, the calculated F-value is less than the critical values obtained from the F-distribution Table, then, the hypothesis is supported because there is no significant difference between the values of thermal conductivity of the samples for different particle sizes for the clay-cow pie mixture ratio of 9:7:4 at both levels of significance of α=0.01 and α=0.05.

Since there was no statistically significant difference between the thermal conductivity values then, the overall thermal conductivity calculated for all the samples was 0.2217±0.0234 W m^{-1} $K^{-1}$and 0.2217 ± 0.0141 $Wm^{-1}K^{-1}$ for levels of significance of α=0.01 and α=0.05 respectively.

Also from Table 4.2, the p-value calculated at a level of significance α=0.05 is less than the level of significance; therefore, the hypothesis is rejected. This implies that there is a significance difference between clay-cow pie particle sizes and the values of thermal conductivity.

4.2.2 Thermal conductivity for mixture ratio of 9:6:5

The second result of thermal conductivity was obtained for kaolin: ball clay: cow pie ratio of 9:6:5. The average thermal conductivity of the five samples of clay particle sizes of 0-74 µm labelled D1, 75-89 µm labelled D2, 90-149 µm labelled D3, 150-299 µm labelled D4 and 300-349 µm labelled D5 was obtained as shown in Table 4.3.

Table 4.3: Average thermal conductivity, standard deviation and maximum error estimate for the ratio 9:6:5

Particle Sizes	**D1**	**D2**	**D3**	**D4**	**D5**
Conductivity (W m^{-1} K^{-1})	0.2240	0.2220	0.2190	0.2200	0.2180
STD (W m^{-1} K^{-1})	0.0046	0.0049	0.0049	0.0037	0.004
Max Error (W m^{-1} K^{-1}) α=0.01	0.0032	0.0095	0.0101	0.0076	0.0082
α=0.05	0.0019	0.0057	0.0061	0.0046	0.0050

To compare the thermal conductivities for the different particle sizes, a bar chart of the conductivity against particle sizes was drawn as shown in Figure 4.2.

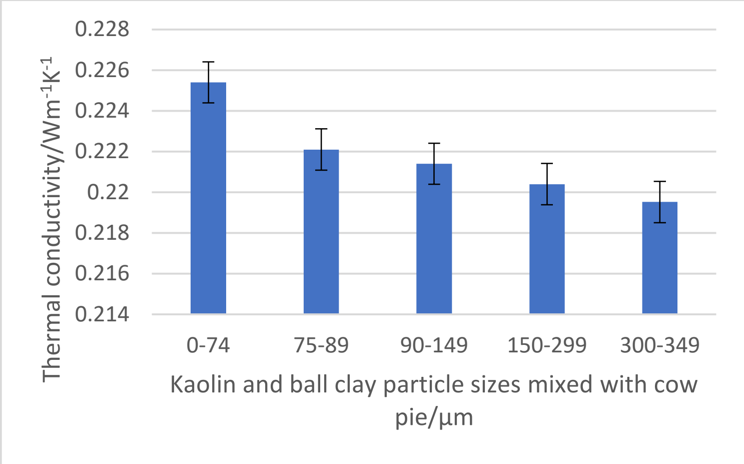

Figure 4.2: A bar chart of thermal conductivity against particle size of kaolin, ball clay mixed with cow pie in the ratio of 9:6:5

The bar chart in Figure 4.2 shows that thermal conductivity values are generally different with the lowest thermal conductivity values as 0.2180 ± 0.0082 W m^{-1} K^{-1} and the highest thermal conductivity values as 0.2240 ± 0.0032 W m^{-1} K^{-1} at level of significance α=0.01 and lowest thermal conductivity values 0.2180± 0.0050 W m^{-1} K^{-1} and the highest thermal conductivity value as 0.2240 ± 0.0019W m^{-1} K^{-1} at levels of significance α=0.05 as the particle sizes of kaolin, ball clay-cow pie decrease for the ratio 9:6:5.
To test if the differences of the thermal conductivity for the different particle sizes were statistically significant, the F-value was determined for the five different mean thermal conductivities at levels of significant α=0.01 and α=0.05 and recorded in Table 4.4.

Table 4.4: F-ratio calculated values and p-value for thermal conductivity for the ratio 9:6:5

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**	**p-value at 0.01**	**p-value at 0.05**
1.9100	4.4300	2.8700	0.0100	0.0498

From Table 4.4, the calculated F-value is less than the critical values obtained from the F-distribution Table, then, the hypothesis is accepted because there is no significant difference between the values of thermal conductivity of the samples for different particle sizes of clay-cow pie ratio 9:6:5. The overall thermal conductivity calculated for all the samples was 0.2201± 0.0250 W m^{-1} K^{-1} and 0.2201 ± 0.0151W m^{-1} K^{-1} at levels of significance α=0.01 and α=0.05 respectively.

However, also from Table 4.4, the calculated p-value is less than the level of significance α=0.05, therefore, the null hypothesis is rejected since there is a statistically significant difference between thermal conductivity values and clay-cow pie particle sizes.

4.2.3 Thermal conductivity for mixture ratio of 9:7:0

The third clay and cow pie ratio considered was 9: 7 :0 and samples were labeled E1 to E5. The average thermal conductivity of each of the samples for clay particle sizes of 0-74 µm labelled E1, 75-89 µm labelled E2, 90-149 µm labelled E3, 150-299 µm labelled E4 and 300-349 µm labelled E5. The results obtained for this ratio are given in Table 4.5.

Table 4.5: Average thermal conductivity values, standard deviation and mean error for the ratio 9:7:0

Particle Sizes	**E1**	**E2**	**E3**	**E4**	**E5**
Conductivity (W m^{-1} K^{-1})	0.2870	0.2780	0.2770	0.2650	0.2510
STD (W m^{-1} K^{-1})	0.0051	0.0098	0.0098	0.0195	0.0242
Max Error ($Wm^{-1}K^{-1}$) α=0.01	0.0105	0.0202	0.0201	0.0402	0.0498
α=0.05	0.0063	0.0122	0.0121	0.0242	0.0300

To compare the thermal conductivity for the different particle sizes, a bar chart of the conductivity against particle sizes was drawn as shown in Figure 4.3.

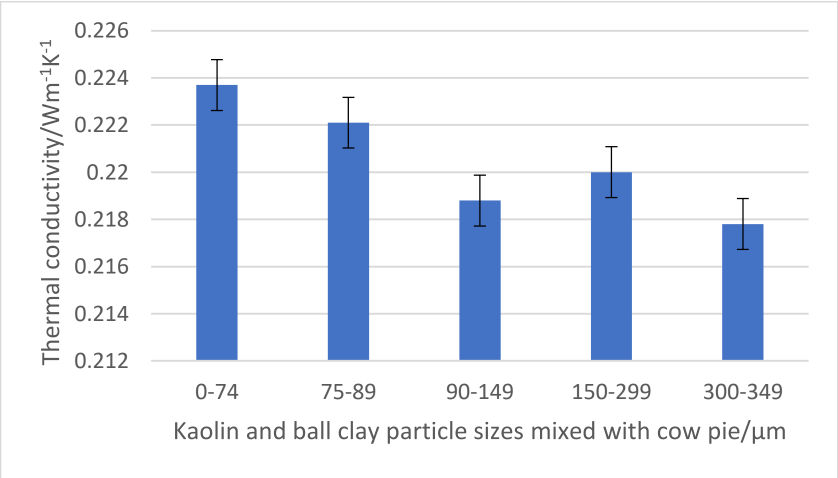

Figure 4.3: A bar chart of thermal conductivity against particle size of kaolin, ball clay mixed with cow pie in the ratio of 9:7:0

The graph in Figure 4.3 shows that thermal conductivity increased from 0.2510 ± 0.0498 W m^{-1} K^{-1} to 0.2870 ± 0.0105 W m^{-1} K^{-1} for the level of significance α=0.01 and from 0.2510 ± 0.030 W m^{-1} K^{-1} to 0.2870 ± 0.0063 $Wm^{-1}K^{-1}$ for the level of significance α=0.05, respectively, with decrease in particle sizes of clay for the ratio 9:7:0. To test if the differences of the thermal conductivity for the different particle sizes were statistically significant, the F-value was determined for the five different mean thermal conductivities at levels of significance α=0.01 and α=0.05 as shown in Table 4.6.

Table 4.6: F-ratio calculated values and p-value for thermal conductivity for the ratio 9:7:0

F- value calculated	**F-value critical at α=0.01**	**F-critical value at α=0.05**	**p-value at 0.01**	**p-value at 0.05**
4.01	4.4300	2.8700	0.0100	0.0498

From Table 4.6, the calculated F-value is less than the critical value obtained from the F-distribution Table at a level of significance α=0.01, then the hypothesis is accepted because there is no significant difference between the values of thermal conductivity. The overall thermal conductivity at confidence level α=0.01 was not affected by the particle sizes of the clays. The overall thermal conductivity at α=0.01 calculated for all the samples was 0.2718 ± 0.1418 W m^{-1} K^{-1}.

However, the calculated F-value is greater than the critical value at level of significance α=0.05, therefore, the hypothesis is rejected because there is a significant difference between the values of thermal conductivity of the samples for different particle sizes for the clay-cow pie ratio 9:7:0 at level of significance α=0.05. The highest thermal conductivity value was 0.2870 ± 0.0105 W m^{-1} K^{-1} and the lowest thermal conductivity value was 0.2510 ± 0.050 W m^{-1} K^{-1} at level of significance α = 0.01.

However, from Table 4.6, the p-value calculated at a level of significance α = 0.01 is equal to the level of significance, this implies that there is too much variability for the hypothesis to test. Therefore, there is a significant difference between the values of thermal conductivity of the samples for different particle sizes of clay-cow pie ratio.

4.2.4 Thermal conductivity for particle size 0-74 µm

This set of result was to determine how thermal conductivity of each particle size varied with the clay-cow pie ratios.

The first result was to find the mean thermal conductivity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The thermal conductivity values of each of the samples of clay-cow pie particle size of 0-74 µm for all the three ratios were obtained and recorded as shown in Table 4.7.

Table 4.7: Average thermal conductivity, standard deviation and maximum error estimate of particle size 0-74 µm for the ratios 9:7:4, 9:6:5 and 9:7:0

Ratio	**9:7:4**	**9:6:5**	**9:7:0**
Conductivity (W m^{-1} K^{-1}	0.2254	0.2237	0.2871
STDV (W m^{-1} K^{-1}	0.0008	0.0015	0.0051
Max Error (W m^{-1} K^{-1} α=0.01	0.0017	0.0032	0.0105
α=0.05	0.0010	0.0019	0.0063

To compare the thermal conductivities for the different ratios, a bar chart of the conductivity against clay-cow pie ratios was drawn as shown in Figure 4.4.

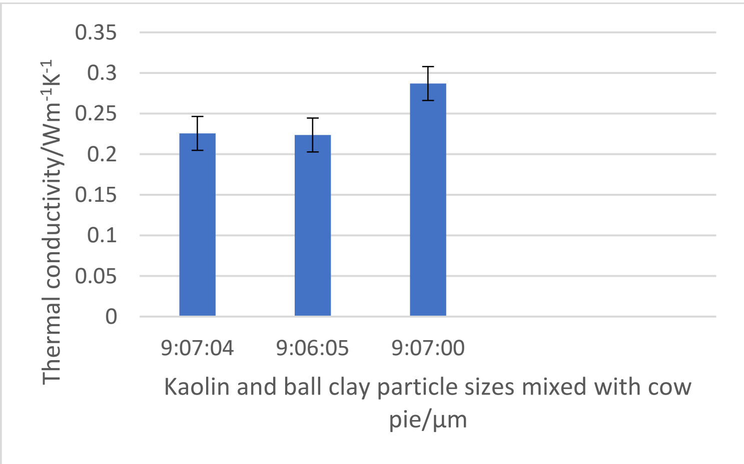

Figure 4.4: A bar chart of thermal conductivity against clay- cow pie ratios

The bar chart in Figure 4.4 shows that thermal conductivity of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the thermal conductivity for the different ratios were statistically significant, the F-value was determined for the mean thermal conductivities at levels of significant α=0.01 and α=0.05 as shown in Table 4.8.

Table 4.8: F-ratio calculated values and p-value for thermal conductivity for particle size 0-74 µm

F- value calculated	F-value critical α=0.01	F-critical value at α=0.05	p-value at α=0.01
6.5400	6.9300	3.8900	0.0276

From Table 4.8, the calculated F-value is less than the critical value from the F-distribution Table, then, the hypothesis is supported because there is no significant difference between the values of thermal conductivity of the samples at level of significance of α=0.01 for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0.

Since there was no statistically significant difference between the thermal conductivity values then, the overall thermal conductivity calculated for all the ratios were 0.2435±0.0743 W m^{-1} K^{-1} for level of significance of α=0.01.

Still from Table 4.8, the calculated p-value is greater than the level of significance but this does not mean that the hypothesis is accepted. Also, if the p-value is greater than the level of significance but less than 0.05 (0.05 is taken to be the level of power for medium effect size at which most behavioral scientists work, Cohen, (1962)). Also, it is at 0.05 where type 11 errors happen. Furthermore, in a study by Cohen, (1994), he noted that the null hypothesis is always false, in other words the null hypothesis at α=0.01 is rejected. Also, such a relationship in the samples only reflects an error and that informally, the null hypothesis "occurred by chance" (Chiang, 2015). In an attempt to explain how low a p-value should be, Chiang, (2015) says that if there is a 5% chance of an outcome as extreme as the sample, then the null hypothesis is rejected and the results are considered to be statistically significant.

However, the calculated F-value is greater than the critical value at level of significance α=0.05. Therefore, the hypothesis is rejected because there is a significant difference between the values of thermal conductivity of the samples for different clay-cow pie ratios at level of significance α=0.05.

4.2.5 Thermal conductivity for particle size 75-89 μm

The second result was to find the mean thermal conductivity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The thermal conductivity values of each of the samples of clay-cow pie particle size of 75-89 μm for all the three ratios were obtained and recorded as shown in Table 4.9.

Table 4.9: Average thermal conductivity, standard deviation and maximum error estimate of particle size of 75-89 μm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio	**9:7:4**	**9:6:5**	**9:7:0**
Conductivity (W m^{-1} K^{-1})	0.2221	0.2221	0.2781
STDV (W m^{-1} K^{-1})	0.0046	0.0039	0.0098
Max Error (W m^{-1} K^{-1}) α=0.01	0.0095	0.0081	0.0202
α=0.05	0.0057	0.0049	0.0122

To compare the thermal conductivities for the different ratios, a bar chart of the conductivity against clay-cow pie ratios was drawn as shown in Figure 4.5.

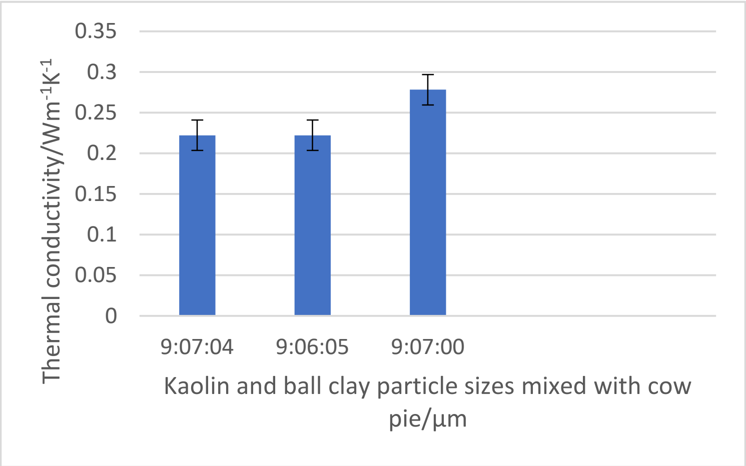

Figure 4.5: A bar chart of thermal conductivity against clay-cow pie ratios

The bar chart in Figure 4.5 shows that thermal conductivity values of the samples for this mixture ratios 9:7:4 and 9:6:5 were the same but different for 9:7:0.

To test if the differences of the thermal conductivity for the different ratios were statistically significant, the F- value was determined for the mean thermal conductivities at levels of significant α=0.01 and α=0.05 as shown in Table 4.10.

Table 4.10: F-ratio calculated values and p-value for thermal conductivity for particle size 75-89 µm

F- value calculated	F-value critical α=0.01	F-critical value at α=0.05	p-value at α=0.01
6.31	6.93	3.89	0.0276

From Table 4.10**,** the calculated F-value is less than the critical value obtained from the F-distribution table, then, the hypothesis is supported because there is no significant difference between the values of thermal conductivity of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at level of significance of α=0.01.

Since there was no statistically significant difference between the thermal conductivity values then, the overall thermal conductivity calculated for all the ratios was 0.2410 ± 0.0666 W m^{-1} K^{-1} for level of significance of α= 0.01.

Also, from Table 4.10, the calculated p-value is greater than the level of significance but this does not mean that the hypothesis is accepted. Also, if the p-value is greater than the level of significance but less than 0.05 (0.05 is taken to be the level of power for medium effect size at which most behavioral scientists work, Cohen, (1962)). Also, it is at 0.05 where type 11 errors happen. Furthermore, in a study by Cohen, (1994), he noted that the null hypothesis is always false, in other words the null hypothesis at α=0.01 is rejected. Also, such a relationship in the samples only reflects an error and that informally, the null hypothesis “occurred by chance” (Chiang, 2015). In an attempt to explain how low a p-value should be, Chiang, (2015) says that if there is a 5% chance of an outcome as extreme as the sample, then the null hypothesis is rejected and the results are considered to be statistically significant.

However, the calculated F-value is greater than the critical value at level of significance α=0.05 therefore, the hypothesis is rejected because there is a significant difference between the values of thermal conductivity of the samples for different clay-cow pie ratios at level of significance α=0.05.

4.2.6 Thermal conductivity for particle size 90-149 µm

The third result was to find the mean thermal conductivity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The thermal conductivity values of each of the samples of clay-cow pie particle size of 90-149 μm for all the three ratios were obtained and recorded as shown in Table 4.11.

Table 4.11: Average thermal conductivity, standard deviation and maximum error estimate of particle size of 90-149 μm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
Conductivity (W m^{-1} K^{-1})		0.2214	0.2188	0.2771
STDV (W m^{-1} K^{-1})		0.0039	0.0049	0.0098
Max Error (W m^{-1} K^{-1})	**α=0.01**	0.0080	0.0101	0.0201
	α=0.05	0.0048	0.0061	0.0121

To compare the thermal conductivities for the different ratios, a bar chart of the conductivity against clay-cow pie ratios was drawn as shown in Figure 4.6.

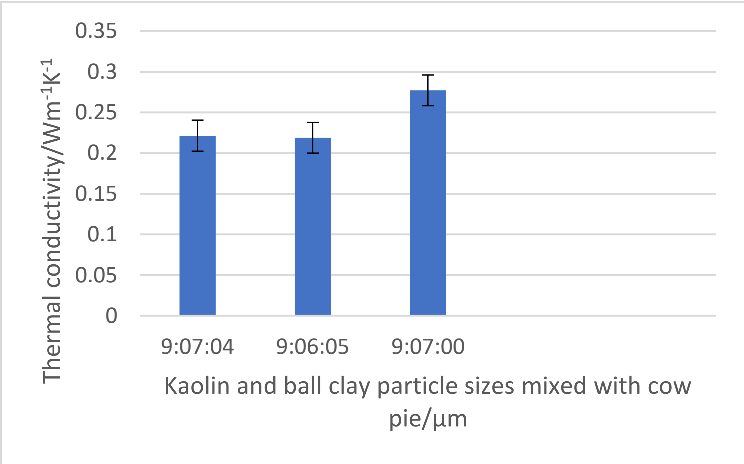

Figure 4.6: A bar chart of thermal conductivity against clay-cow pie ratios

The bar chart in Figure 4.6 shows that thermal conductivity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the thermal conductivity for the different ratios were statistically significant, the F- value was determined for the mean thermal conductivities at levels of significant α=0.01 and α=0.05 as shown in Table 4.12.

Table 4.12: F-ratio calculated values and the p-value for thermal conductivity for particle size 90-149 µm

F- value calculated	F-value critical α=0.01	F-critical value at α=0.05	p-value at α=0.01
6.2900	6.9300	3.8900	0.0276

From Table 4.12**,** the calculated F-value is less than the critical value obtained from the F-distribution table, then, the hypothesis is supported because there is no significant difference between the values of thermal conductivity of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at level of significance of α=0.01.

Since there was no statistically significant difference between the thermal conductivity values then, the overall thermal conductivity calculated for all the ratio was
0.2373 ± 0.0678 W m^{-1} K^{-1} for level of significance of α=0.01.

Also, from Table 4.12, the calculated p-value is greater than the level of significance but this does not mean that the hypothesis is accepted. Also, if the p-value is greater than the level of significance but less than 0.05 (0.05 is taken to be the level of power for medium effect size at which most behavioral scientists work, Cohen, (1962)). Also, it is at 0.05 where type 11 errors happen. Furthermore, in a study by Cohen, (1994), he noted that the null hypothesis is always false, in other words the null hypothesis at α=0.01 is rejected. Also, such a relationship in the samples only reflects an error and that informally, the null hypothesis "occurred by chance" (Chiang, 2015). In an attempt to explain how low a p-value should be, Chiang, (2015) says that if there is a 5% chance of an outcome as extreme as the sample, then the null hypothesis is rejected and the results are considered to be statistically significant.

However, the calculated F-value is greater than the critical value at level of significance α=0.05. Therefore, the hypothesis is rejected because there is a significant difference between the values of thermal conductivity of the samples for different clay-cow pie ratios at level of significance α=0.05.

4.2.7 Thermal conductivity for particle size 150-299 µm

The fourth result was to find the mean thermal conductivity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The thermal conductivity values of each of the samples of clay-cow pie particle size of 150 - 299 µm for all the three ratios were obtained and recorded as shown in Table 4.13.

Table 4.13: Average thermal conductivity, standard deviation and maximum error estimate of particle size of 150-299 μm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
Conductivity (W m^{-1} K^{-1})		0.2204	0.2200	0.2654
STDV (W m^{-1} K^{-1})		0.0039	0.0037	0.0195
Max Error (Wm^{-1}K^{-1})	**α=0.01**	0.0081	0.0076	0.0402
	α=0.05	0.0049	0.0046	0.0242

To compare the thermal conductivities for the different ratios, a bar chart of the conductivity against clay-cow pie ratios was drawn as shown in Figure 4.7.

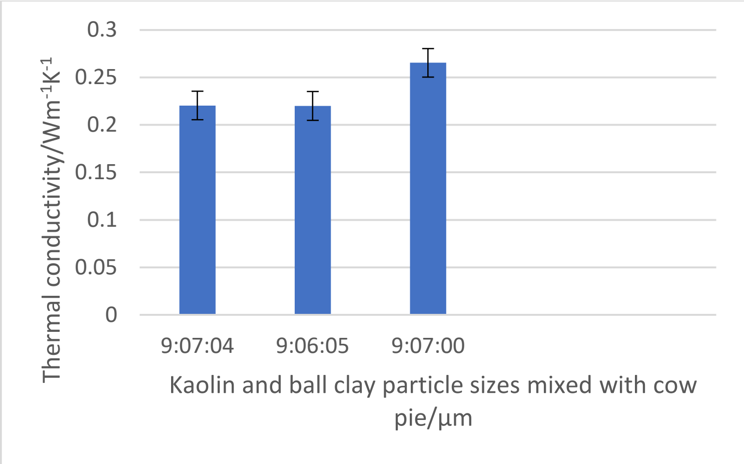

Figure 4.7: A bar chart of thermal conductivity against clay-cow pie ratios

The bar chart in Figure 4.7 shows that thermal conductivity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the thermal conductivity for the different ratios were statistically significant, the F-value was determined for the mean thermal conductivities at levels of significant α=0.01 and α=0.05 as shown in Table 4.14.

Table 4.14: F-ratio calculated values for thermal conductivity for particle size 150-299 μm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
7.4400	6.9300	3.8900

From Table 4.14, the calculated F-value is greater than the critical value from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of thermal conductivity of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at both level of significance of $\alpha=0.01$ and $\alpha=0.05$.

4.2.8 Thermal conductivity for particle size 300-349 μm

The fifth result was to find the mean thermal conductivity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The thermal conductivity values of each of the samples of clay-cow pie particle size of 300-349 μm for all the three ratios were obtained and recorded as shown in Table 4.15.

Table 4.15: Average thermal conductivity, standard deviation and maximum error estimate of particle size of 300-349 μm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
Conductivity/ W m^{-1} K^{-1}		0.2195	0.2178	0.2514
STDV/ W m^{-1} K^{-1}		0.0045	0.0040	0.0242
Max Error/ W m^{-1} K^{-1}	**α=0.01**	0.0092	0.0082	0.0498
	α=0.05	0.0056	0.0050	0.0300

To compare the thermal conductivities for the different ratios, a bar chart of conductivity against clay-cow pie ratios was drawn as shown in Figure 4.8.

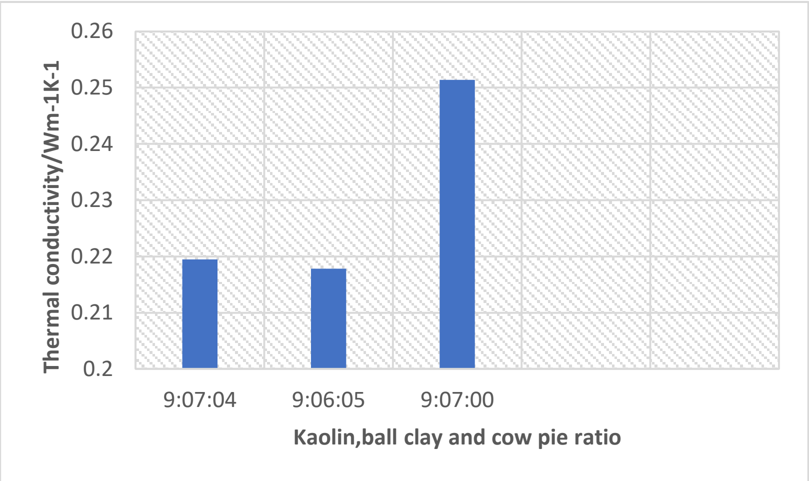

Figure 4.8: A bar chart of thermal conductivity against clay-cow pie ratios

The bar chart in Figure 4.8 shows that thermal conductivity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the thermal conductivity for the different ratios were statistically significant, the F-value was determined for the mean thermal conductivities at levels of significant α=0.01 and α=0.05 as shown in Table 4.16.

Table 4.16: F-ratio calculated values for thermal conductivity for particle size 300-345 µm

F- value calculated	F-value critical α=0.01	F-critical value at α=0.05
10.1700	6.9300	3.8900

From Table 4.16, the calculated F-value is greater than the critical value from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of thermal conductivity of the samples for the clay-cow pie mixture ratios of 9:7:4 ,9:6:5 and 9:7:0 at both levels of significance of α=0.01 and α=0.05.

4.2.9 Conclusion on the effect of particle size and mixture ratio on thermal conductivity

Table 4.17: Summary of the decision made on the null hypothesis, HO1 set in Section 1.

Clay-cow pie ratio/particle size	Decision on the null hypothesis
9:7:4	Rejected
9:6:5	Rejected
9:7:0	Rejected
0-74	Rejected
75-89	Rejected
90-149	Rejected
150-299	Rejected
300-349	Rejected

4.2.9.1 Effect of particle size on thermal conductivity

Reducing the particle size of kaolin and ball clay of a brick sample increased the thermal conductivity. The effect of particle size of kaolin and ball clay is related to the amount of air space and the length of the solid through which the heat has to travel. This is because small particle sizes result into proper filling up of voids as compared to large particle sizes that result into poor filling up of voids (Meena, 2011). If the air spaces are large, the thermal conductivity reduces because these air spaces retard the rate of heat flow.

The absence of a pore former resulted into an increase in the value of thermal conductivity because on heating the brick samples, no voids were created and so the rate of heat conduction increased. Also, an increase in thermal conductivity was associated closely with a reduction in porosity and better interlocking of clay particles.

4.2.9.2 Effect of change of ratio on thermal conductivity

There was a statistically significant difference between the values of thermal conductivity of the samples for different particle sizes at levels of significance α =0.01 and α =0.05, Also, there was a statistically significant difference between the values of thermal conductivity for the different clay-cow pie ratios and this may be because for the clay-cow pie ratio 9:6:5 as compared to clay-cow pie ratio 9:7:4, more air spaces were created as a result of increased amount of pore former used. Therefore, the thermal conductivity reduced because these air spaces retard the rate of heat flow. Thermal conductivity for the control experiment was high because of the absence of the pore former.

4.3 Density of the samples

The second objective of the study was to determine the density of the samples produced for the three different clay cow pie ratios of 9:7:4, 9:6:5 and 9:7:0 for the five different particle sizes of 0-74 µm, 75-89 µm, 90-149 µm, 150-299 µm and 300-349 µm.

4.3.1 Density of samples for mixture ratio of 9:7:4

The densities of the samples for clay-cow pie ratio of 9:7:4 and samples were obtained for samples labeled A1 to A5 for clay-cow pie particle sizes of 0-74 µm, 75-89 µm, 90-149 µm, 150-299 µm and 300-349 µm respectively. The average values for the different particle sizes obtained for this ratio were as given in Table 4.18.

Table 4.18: Average density values, standard deviation and maximum error estimate for the ratio 9:7:4

SAMPLES		A1	A2	A3	A4	A5
Density (g cm^{-3})		1.1830	1.1540	1.1540	1.1430	1.1490
STD (g cm^{-3})		0.0180	0.0441	0.0176	0.0311	0.0156
Max Error (gcm^{-3})	**α=0.01**	0.0370	0.0908	0.0362	0.0640	0.0320
	α=0.05	0.0223	0.0547	0.0218	0.0386	0.0193

To compare the densities for the different particle sizes a bar chart of density against particle sizes was drawn as shown in Figure 4.9.

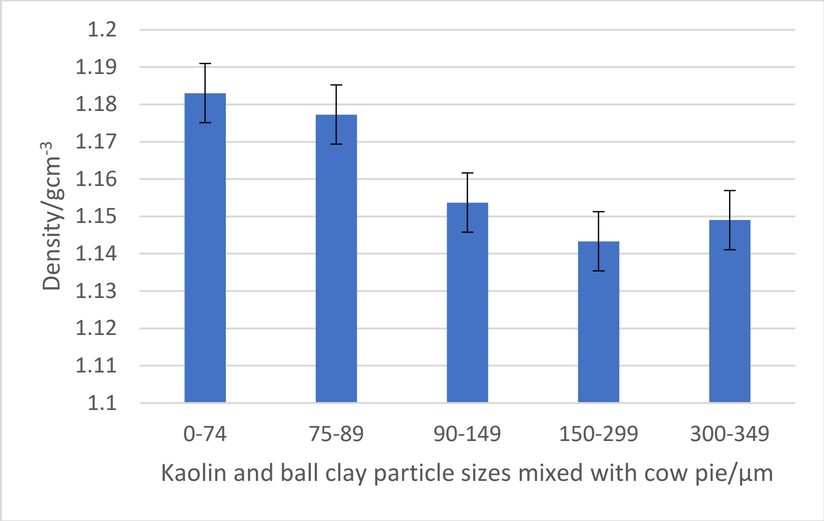

Figure 4.9: A bar chart of density against particle size of kaolin, ball clay mixed with cow pie in the ratio of 9:7:4

From Figure 4.9, the density is different for different particle size of samples for the clay-cow pie ratio 9:7:4. The lowest density values determined were 1.1430 ± 0.0640 g cm^{-3} and the highest density value were 1.1830 ± 0.0370 g cm^{-3} at level of significance α=0.01 and lowest density values were 1.1430 ± 0.0386 g cm^{-3} and the highest density value were 1.1830 ± 0.0223 g cm^{-3} at level of significance α=0.05 respectively.

To test if the differences of the density for the different particle sizes were statistically significant, the F-value was determined for the five different mean densities at levels of significance α=0.01 and α=0.05 and recorded in Table 4.19.

Table 4.19: F-ratio calculated values for density for the ratio 9:7:4

F- value calculated	F-value critical α=0.01	F-critical value at α=0.05
6.5700	4.4300	2.8700

From Table 4.18, the calculated F-value is greater than the critical values obtained from the F-distribution Table then, the hypothesis is rejected because there is a significant difference between the values of density of the samples for different particle sizes for the clay-cow pie ratio 9:7:4 at both levels of significance α=0.01 and at α=0.05.

The overall density at confidence level α=0.01 and α=0.05 was affected by the particle sizes of the clays.

4.3.2 Density of samples for mixture ratio of 9:6:5

The second result was to find the densities of samples produced using clay: cow pie ratio of 9:6:5 of different particle sizes labeled D1 to D5. The average density of each of the samples for clay particle sizes of 0-74 µm labelled D1, 75-89 µm labelled D2, 90-149 µm labelled D3, 150-299 µm labelled D4 and 300-349 µm labelled D5. The results of density obtained for this ratio are given in Table 4.20.

Table 4.20: Average density values, standard deviation and maximum error estimate for the ratio 9:6:5

Particle Sizes	D1	D2	D3	D4	D5
Density (g cm^{-3})	1.1870	1.1660	1.1950	1.1790	1.2000
STDV (g cm^{-3})	0.0103	0.0542	0.0337	0.0241	0.0853
Max Error (g cm^{-3}) α=0.01	0.0251	0.0230	0.0436	0.0884	0.0650
α=0.05	0.0152	0.0139	0.0263	0.0533	0.0392

To compare the densities for the different particle sizes a bar chart of density against particle sizes was drawn as shown in Figure 4.10.

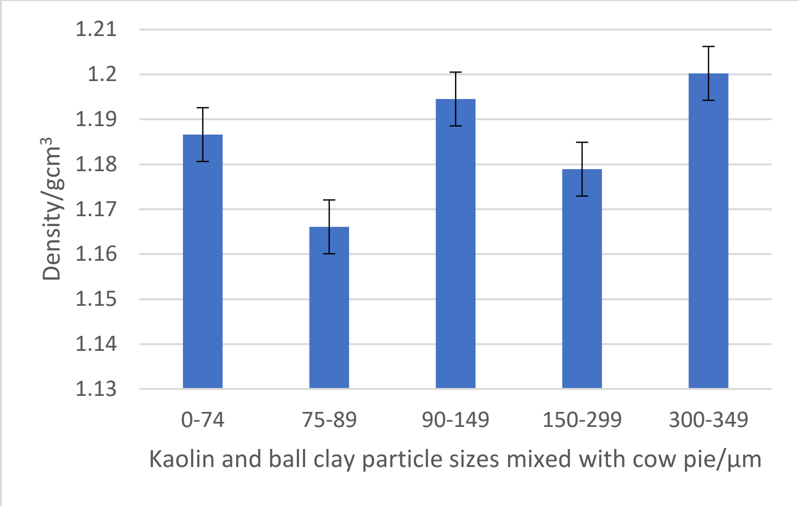

Figure 4.10: A bar chart of density against particle size of kaolin, ball clay mixed with cow pie in the ratio of 9:6:5

The graph in Figure 4.10 shows that the values of densities are different for the different particle sizes of samples for the clay-cow pie ratio 9:6:5. The lowest density values determined were 1.1660 ± 0.0230 gcm^{-3} and the highest density value were 1.2000 ± 0.0650 gcm^{-3} at level of significance α=0.01 and lowest density values 1.166 ± 0.0139 gcm^{-3} and the highest density value were 1.2000 ± 0.0392 gcm^{-3} at α=0.05 respectively.

To test if the differences of the density for the different particles size were statistically significant, the F-value was determined for the five different mean densities at levels of significant α=0.01 and α=0.05 and values were recorded in Table 4.21.

Table 4.21: F-ratio calculated values for density for the ratio 9:6:5

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
5.3700	4.4300	2.8700

From Table 4.21, the calculated F-value is greater than the critical value obtained from the F-distribution Table then, the hypothesis is rejected because there is a significant difference between the values of density of the samples for different particle sizes for the clay-cow pie ratio 9:6:5 at levels of significance α=0.05 and α=0.01.

The overall density at confidence level α=0.01 and α=0.05 was affected by the particle sizes of the clays.

4.3.3 Density of samples for mixture ratio of 9:7:0

The third clay: cow pie ratio considered was 9:7:0 and samples were labeled E1 to E5. The average density of each of the samples for clay particle sizes of 0-74 µm labelled E1, 75-89 µm labelled E2, 90-149 µm labelled E3, 150-299 µm labelled E4 and 300-349 µm labelled E5. The results obtained for this ratio are given in Table 4.22.

Table 4.22: Average density values, standard deviation and maximum error estimate for the ratio 9:7:0

SAMPLES	E1	E2	E3	E4	E5
Density (g cm^{-3})	1.1690	1.1580	1.1380	1.1450	1.1260
STDV (g cm^{-3})	0.0122	0.0112	0.0212	0.0429	0.0316
Max Error (g cm^{-3}) α=0.01	0.0212	0.1117	0.0694	0.0496	0.1756
α=0.05	0.0128	0.0673	0.0418	0.0299	0.1059

To compare the densities for the different particle sizes a bar chart of density against particle sizes was drawn as shown in Figure 4.11.

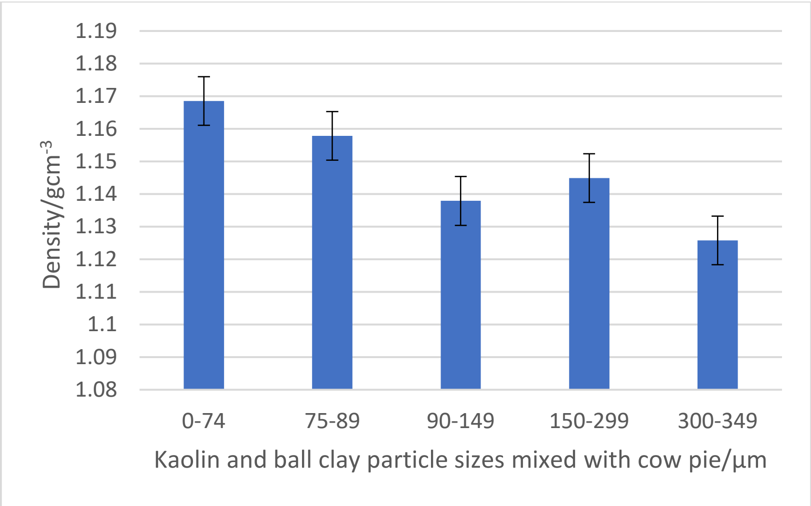

Figure 4.11: A bar chart of density against particle size of kaolin, ball clay mixed with cow pie in the ratio of 9:7:0

From Figure 4.11, the densities for the different particle sizes of samples for the ratio 9:7:0 were different. The lowest density value determined was 1.1260 ± 0.1756 gcm^{-3} and the highest density value was 1.1690 ± 0.0212 gcm^{-3} at level of significance α=0.01, the lowest density value was 1.1260 ± 0.1059 gcm^{-3} and the highest density value was

1.1690 ± 0.0128 gcm^{-3} at and α=0.05 respectively.

To test if the differences of the densities for the different particle sizes were statistically significant, the F-value was determined for the five different mean densities at levels of significance α=0.01 and α=0.05 and recorded in Table 4.23.

Table 4.23: F-ratio calculated values for density for the ratio 9:7:0

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
6.9500	4.4300	2.8700

From Table 4.23, the calculated F-value is greater than the critical value in the F-distribution, Table, then, the hypothesis is rejected because there is a significant difference between the values of density of the samples for different particle sizes for the clay-cow pie ratio 9:7:0 at levels of significance α=0.01 and α=0.05.

The overall density at confidence level α=0.01 and α=0.05 was affected by the particle sizes of the clays and cow pie.

4.3.4 Density for particle size 0-74 µm

This set of result was to determine how density of each particle size varied with the clay-cow pie ratios.

The first result was to find the mean density of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The density values of each of the samples of clay-cow pie particle size of 0-74 µm for all the three ratios were obtained and recorded as shown in Table 4.24.

Table 4.24: Average density, standard deviation and maximum error estimate of particle size 0-74 µm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
Density (g cm^{-3})		1.1830	1.1866	1.1685
STDV (g cm^{-3})		0.0180	0.0103	0.0122
Max Error (g cm^{-3})	**α=0.01**	0.0370	0.0212	0.0251
	α=0.05	0.0223	0.0128	0.0152

To compare densities for the different ratios, a bar chart of density against clay-cow pie ratios was drawn as shown in Figure 4.12.

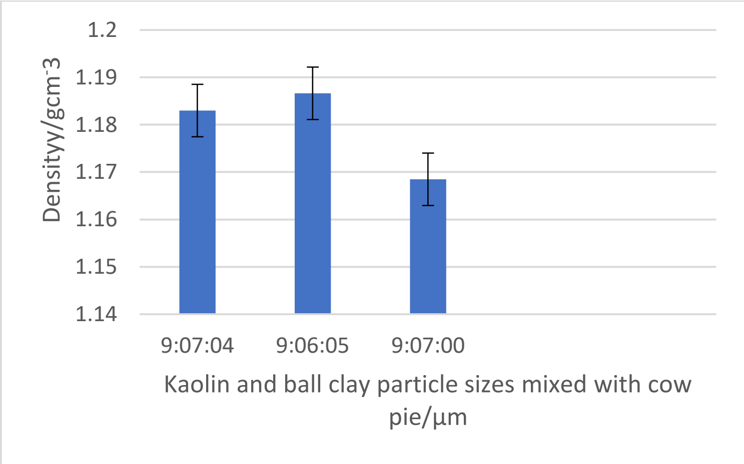

Figure 4.12: A bar chart of density against clay- cow pie ratios

The bar chart in Figure 4.12 shows that the density values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the densities for the different ratios were statistically significant, the F- value was determined for the mean thermal conductivities at levels of significant α=0.01 and α=0.05 as shown in Table 4.25.

Table 4.25: F-ratio calculated values for density for particle size 0-74 µm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
21.1100	6.9300	3.8900

From Table 4.25, the calculated F-value is greater than the critical value from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of density of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at both level of significance of α=0.01 and α=0.05.

4.3.5 Density for particle size 75-89 µm

The second result was to find the mean density of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The density values of each of the samples of clay-cow pie particle size of 75-89 µm for all the three ratios were obtained and recorded as shown in Table 4.26.

Table 4.26: Average density, standard deviation and maximum error estimate of particle size 75-89 µm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio	**9:7:4**	**9:6:5**	**9:7:0**
Density (gcm^{-3})	1.1535	1.1661	1.1578
STDV (gcm^{-3})	0.0441	0.0542	0.0112
Max Error (gcm^{-3}) α=0.01	0.0908	0.0117	0.0230
α=0.05	0.0547	0.0673	0.0139

To compare the densities for the different ratios, a bar chart of the conductivity against clay-cow pie ratios was drawn as shown in Figure 4.13.

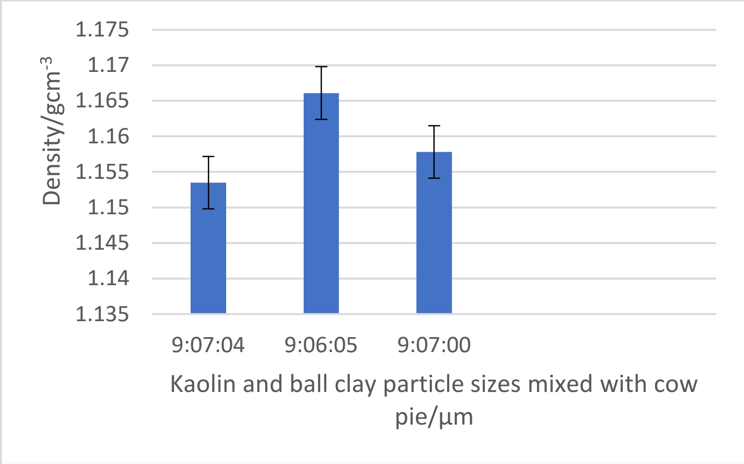

Figure 4.13: A bar chart of density against clay- cow pie ratios

The bar chart in Figure 4.13 shows that the density values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the densities for the different ratios were statistically significant, the F-value was determined for the mean thermal conductivities at levels of significant α=0.01 and α=0.05 as shown in Table 4.27.

Table 4.27: F-ratio calculated values for density for particle size 75-89 µm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
298.8800	6.9300	3.8900

From Table 4.27, the calculated F-value is greater than the critical value obtained from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of density of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at both levels of significance of α=0.01 and α=0.05.

4.3.6 Density for particle size 90 - 149 µm

The third result was to find the mean density of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The density values of each of the samples of clay-cow pie particle size of 90 - 149 µm for all the three ratios were obtained and recorded as shown in Table 4.28.

Table 4.28: Average density, standard deviation and maximum error estimate of particle size of 90 - 149 µm for the ratio 9:7:4, 9:6:5 and 9:7:0.

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
Density (g cm^{-3})		1.3321	1.3312	1.1379
STDV (g cm^{-3})		0.0995	0.0405	0.0212
Max Errors (g cm^{-3})	**α=0.01**	0.2049	0.0834	0.0436
	α=0.05	0.1235	0.0503	0.0263

To compare the densities for the different ratios, a bar chart of density against clay-cow pie ratios was drawn as shown in Figure 4.14.

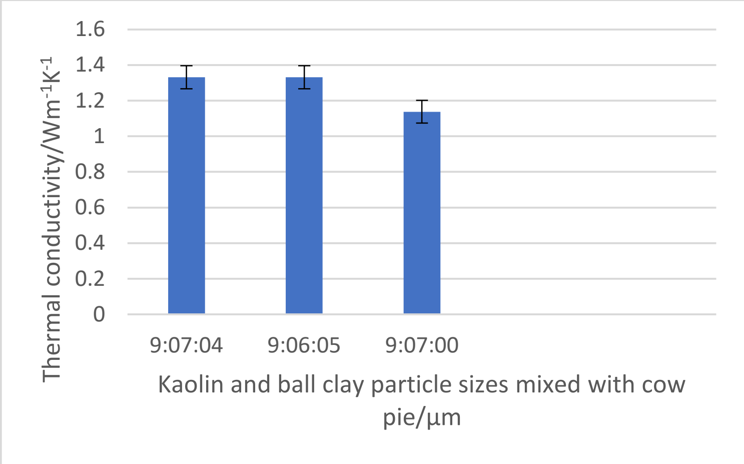

Figure 4.14: A bar chart of density against clay-cow pie ratios

The bar chart in Figure 4.14 shows that the density values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the densities for the different ratios were statistically significant, the F-value was determined for the mean density at levels of significant α=0.01 and α=0.05 as shown in Table 4.29.

Table 4.29: F-ratio calculated values and p-values for density for particle size 90 - 149 µm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**	**p-value at α=0.01**	**p-value at α=0.05**
-281.3600	6.9300	3.8900	0.0276	0.0276

From Table 4.29, the calculated F-value is less than the critical value obtained from the F-distribution Table, then, the hypothesis is accepted because there is no significant difference between the values of density of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at both levels of significance of α=0.01 and α=0.05. The overall densities at both levels of significance α=0.01 and α=0.05 are 6.3354 ± 0.0840 gcm^{-3} and 6.3354 ± 0.0507 gcm^{-3}.

Also, from Table 4.29, the calculated p-value is greater than the level of significance α=0.01 but this does not mean that the hypothesis is accepted. Also, if the p-value is greater than the level of significance but less than 0.05 (0.05 is taken to be the level of power for medium effect size at which most behavioral scientists work, Cohen, (1962)). Also, it is at 0.05 where type 11 errors happen. Furthermore, in a study by Cohen, (1994), he noted that the null hypothesis is always false, in other words the null hypothesis at α=0.01 is rejected. Also, such a relationship in the samples only reflects an error and that informally, the null hypothesis "occurred by chance" (Chiang, 2015). In an attempt to explain how low a p-value should be, Chiang, (2015) says that if there is a 5% chance of an outcome as extreme as the sample, then the null hypothesis is rejected and the results are considered to be statistically significant.

However, the calculated p-value at α=0.05 is less than the level of significance, therefore, the hypothesis is finally rejected because there is a significant difference between density values and clay-cow pie ratios.

4.3.7 Density for particle size 150-299 μm

The fourth result was to find the mean density of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The density values of each of the samples of clay-cow pie particle size of 150-299 μm for all the three ratios were obtained and recorded as shown in Table 4.30.

Table 4.30: Average density, standard deviation and maximum error estimate of particle size of 150-299 μm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
Density (g cm^{-3})		1.1433	1.1789	1.1145
STDV (g cm^{-3})		0.0311	0.0241	0.0429
Max Error (g cm^{-3})	**α=0.01**	0.0640	0.0496	0.0884
	α=0.05	0.0386	0.0299	0.0533

To compare the densities for the different ratios, a bar chart of density against clay-cow pie ratios was drawn as shown in Figure 4.15.

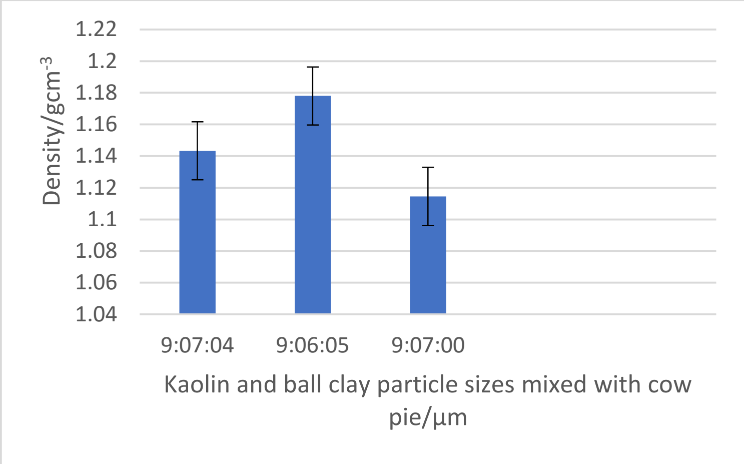

Figure 4.15: A bar chart of density against clay-cow pie ratios

The bar chart in Figure 4.15 shows that the density values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the densities for the different ratios were statistically significant, the F-value was determined for the mean thermal conductivities at levels of significant $\alpha=0.01$ and $\alpha=0.05$ as shown in Table 4.31.

Table 4.31: F-ratio calculated values for density for particle size 150-299 µm

F-value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
26.0900	6.9300	3.8900

From Table 4.31, the calculated F-value is greater than the critical value obtained from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of density of the samples for the clay-cow pie mixture ratios of 9:7:4 ,9:6:5 and 9:7:0 at both levels of significance of $\alpha=0.01$ and $\alpha=0.05$.

4.3.8 Density for particle size 300-349 µm

The fifth result was to find the mean density of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The density values of each of the samples of clay-cow pie particle size of 300-349 µm for all the three ratios were obtained and recorded as shown in Table 4.32.

Table 4.32: Average density, standard deviation and maximum error estimate of particle size of 300-349 µm for the ratio 9:7:4, 9:6:5 and 9:7:0.

Ratio	**9:7:4**	**9:6:5**	**9:7:0**
Density/ gcm^{-3}	1.1490	1.2002	1.1258
STDV/ gcm^{-3}	0.0156	0.0853	0.0316
Max Error/ gcm^{-3}α=0.01	0.0320	0.1756	0.0650
α=0.05	0.0193	0.1059	0.0392

To compare the densities for the different ratios, a bar chart of density against clay-cow pie ratios was drawn as shown in Figure 4.16.

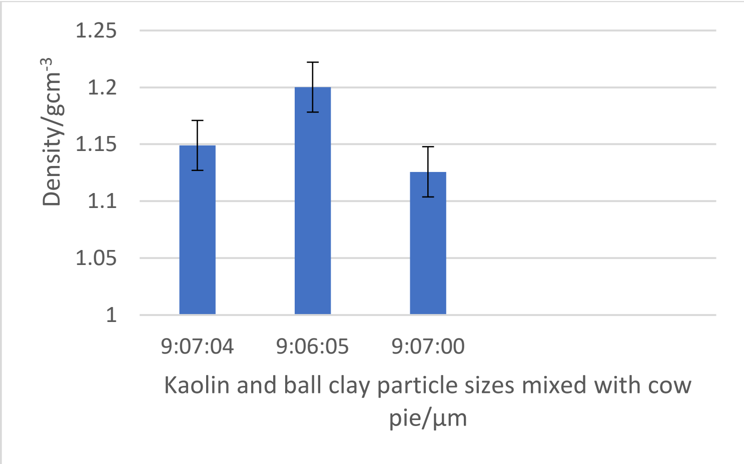

Figure 4.16: A bar chart of density against clay cow pie ratios

The bar chart in Figure 4.16 shows that the density values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the densities for the different ratios were statistically significant, the F-value was determined for the mean thermal conductivities at levels of significant α=0.01 and α=0.05 as shown in Table 4.33.

Table 4.33: F-ratio calculated values for density for particle size 300-349 µm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
20.0900	6.9300	3.8900

From Table 4.33, the calculated F-value is greater than the critical value obtained from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference

between the values of density of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at both level of significance of α=0.01 and α=0.05.

4.3.9 Conclusion on the effect of particle size and mixture ratio on density

Table 4.34: Summary of the decision made on the null hypothesis, H_{O2} set in Section 1.

Clay-cow pie ratio/particle size	Decision on the null hypothesis
9:7:4	Rejected
9:6:5	Rejected
9:7:0	Rejected
0-74	Rejected
75-89	Rejected
90-149	Rejected
150-299	Rejected
300-349	Rejected

4.3.9.1 Effect of particle size on density

Decreasing the particle size of kaolin and ball clay at fixed particle size of cow pie changed the density of the brick sample. The effect of particle size on density may be attributed to the number of particle content per unit volume which results into an increased magnitude of length of the average inter-particle distance. This results into closed pores which lead into an increase in density (Viruthagari *et al.*, 2011). Also, small particle sizes result into proper filling up of voids resulting into a low porosity compared to large particle sizes which result into a high porosity because of poor filling up of voids (Meena, 2011).

4.3.9.2 Effect of change of ratio on density

There was no statistically significant difference between the values of density of the samples for different particle sizes at level of significance α =0.01, however, at α =0.05, the density was different for different particle sizes of samples for the clay-cow pie ratio 9:7:4, 9:6:5 and 9:7:0. Increasing the amount of pore former generally increased the density of the brick sample because during pressing and firing, the voids could have closed and also there was probably no improvement in contact points between the solid particles (Obwoya, 2010).

Brick samples made without incorporating a pore former generally had a low density because of their small volume since less composite was used.

4.4 Specific heat capacity of the samples

The third objective of this study was to obtain specific heat capacity values of the samples produced from five different particle sizes 0-74, 75-89, 90-149, 150-299 and 300-349 µm of three clays: cow pie ratios.

4.4:1 Specific heat capacity of the samples for the ratio 9:7:4

The first clay: cow pie ratio considered was 9:7:4 and samples were labeled A1 to A5. The average specific heat capacity values of each of the samples for clay particle sizes of 0-74 µm labelled A1, 75-89 µm labelled A2, 90-149 µm labelled A3, 150-299 µm labelled A4 and 300-349 µm labelled A5 obtained for this ratio are given in Table 4.35.
Specific heat capacity of each sample was calculated by using the data in Appendix A.

Table 4.35: Average specific heat capacity values, standard deviation and maximum error estimate for the ratio 9:7:4

SAMPLES	A5	A4	A3	A2	A1
Specific heat capacity ($Jg^{-1}\,{}^{0}C^{-1}$)	1.0670	1.0510	0.9810	1.0490	1.0100
STD ($Jg^{-1}\,{}^{0}C^{-1}$)	0.0090	0.0110	0.0140	0.0230	0.0060
Max Error ($Jg^{-1}\,{}^{0}C^{-1}$) α=0.01	0.0119	0.0480	0.0291	0.0226	0.0189
α=0.05	0.0072	0.0290	0.0176	0.0136	0.0114

To compare the specific heat capacities for the different particle sizes, a bar chart of specific heat capacity against particle sizes was drawn as shown in Figure 4.17.

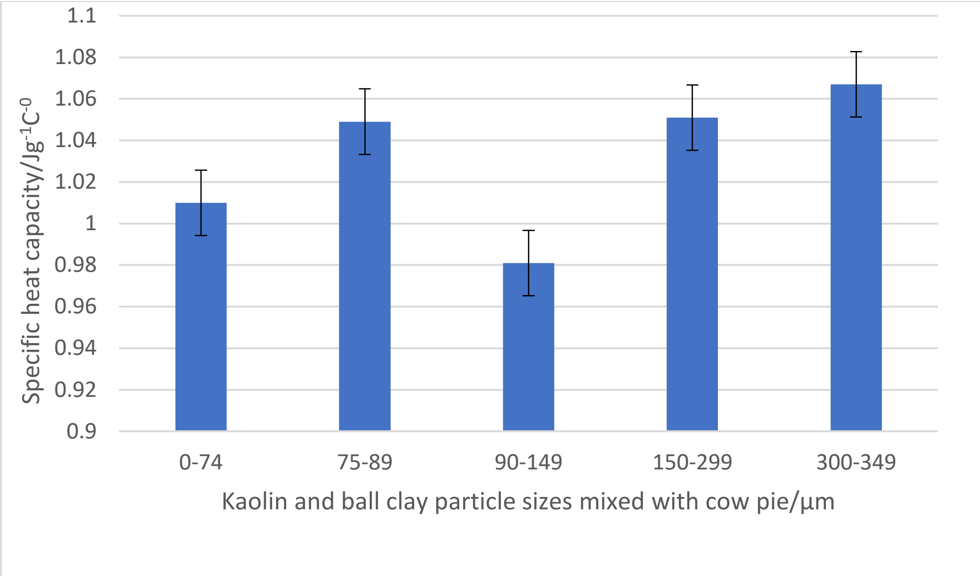

Figure 4.17: A bar chart of specific heat capacity against particle size of kaolin, ball clay mixed with cow pie in the ratio of 9:7:4

From Figure 4.17, the specific heat capacity values are different for different particle sizes of the samples for the clay-cow pie ratio 9:7:4. The lowest specific heat capacity values were 0.9810 ± 0.0291 $Jg^{-1}\,{}^{0}C^{-1}$ and the highest specific heat capacity values were 0.9810 ± 0.0176 $Jg^{-1}\,{}^{0}C^{-1}$ for the level of significance α=0.01 and lowest specific heat capacity values were 1.0670 ± 0.0119 $Jg^{-1}\,{}^{0}C^{-1}$ and the highest specific heat capacity values were 1.0670 ± 0.0072 $Jg^{-1}\,{}^{0}C^{-1}$ for the level of significance α=0.05.

To test if the differences of the specific heat capacity for the different particle sizes were statistically significant, the F-value was determined for the five different mean specific heat capacities at levels of significant α=0.01 and α=0.05 as shown in Table 4.36.

Table 4.36: F-values calculated for specific heat capacity for the clay-cow pie ratio 9:7:4

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
31.900	4.4300	2.8700

From Table 4.36, the calculated F-value is greater than the critical value obtained from the F-distribution Table, then the hypothesis is rejected because there is a significant difference between the values of specific heat capacity of the samples for different particle sizes for the clay-cow pie ratio 9:7:4 at both levels of significance α=0.01 and α=0.05.

4.4.2 Specific heat capacity of the samples for the ratio 9.6.5

The second clay: cow pie ratio considered was 9:6:5 and samples were labeled D1 to D5. The average specific heat capacity values of each of the samples for clay-cow pie particle sizes of 0-74 µm labelled D1, 75-89 µm labelled D2, 90-149 µm labelled D3, 150-299 µm labelled D4 and 300-349 µm labelled D5 obtained for this ratio are given in Table 4.37.

Table 4.37: Average specific heat capacity values, standard deviation and maximum error estimate for the ratio 9:6:5

SAMPLES	D5	D4	D3	D2	D1
Specific heat capacity ($Jg^{-1 0}C^{-1}$)	1.0490	1.0810	1.0630	1.0450	1.0020
STD ($Jg^{-1 0}C^{-1}$)	0.0170	0.0090	0.0190	0.0080	0.0090
Max Error ($Jg^{-1 0}C^{-1}$) α=0.01	0.0185	0.0157	0.0384	0.0175	0.0342
α=0.05	0.0111	0.0095	0.0231	0.0106	0.0206

To compare the specific heat capacities for the different particle sizes, a bar chart of specific heat capacity against particle sizes was drawn as shown in Figure 4.18.

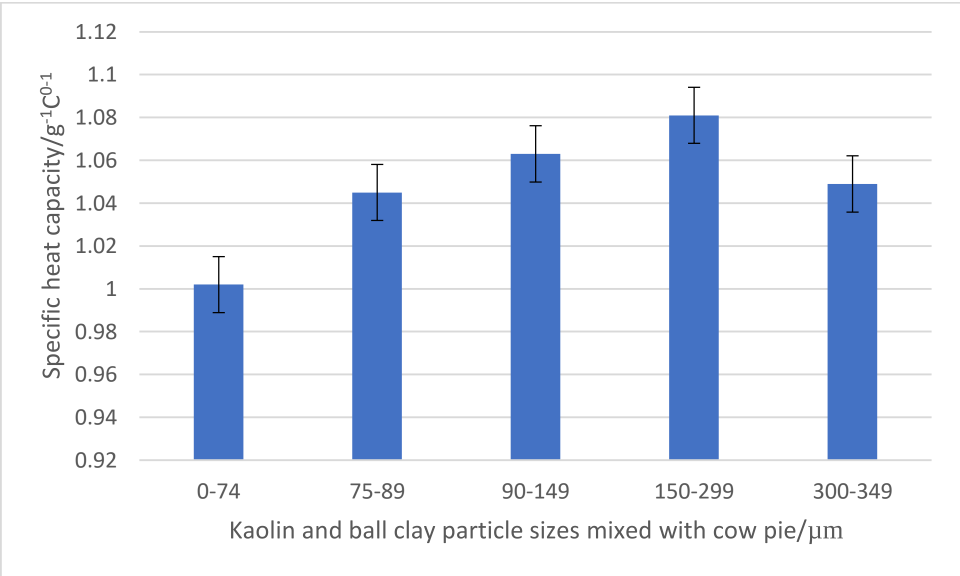

Figure 4.18: A bar chart of specific heat capacity against particle size of kaolin, ball clay mixed with cow pie in the ratio of 9:6:5

From Figure 4.18, the specific heat capacity values are different as the particle size of samples for the clay-cow pie ratio 9:6:5 increase. The lowest specific heat capacity values were 1.0020 ± 0.0342 $Jg^{-1}\,{}^{0}C^{-1}$ the highest specific heat capacity values were 1.0810 ± 0.0157 $Jg^{-1}\,{}^{0}C^{-1}$ at level of significance α=0.01and lowest specific heat capacity values were 1.0020 ± 0.0206 $Jg^{-10}C^{-1}$ and the highest specific heat capacity values were 1.0810 ± 0.0095 $Jg^{-1}\,{}^{0}C^{-1}$ for the level of significance α=0.05 respectively.

To test if the differences of the specific heat capacity for the different particle sizes were statistically significant, the F-value was determined for the five different mean specific heat capacities at levels of significant α=0.01 and α=0.05 as shown in Table 4.38.

Table 4.38: F-value calculated for specific heat capacity for the ratio 9:6:5

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
26.2000	4.4300	2.8700

From Table 4.38, the calculated specific heat capacity F-value is greater than the critical values obtained from the F-distribution Table then, the hypothesis is rejected since there is a significant difference between the values of specific heat capacity of the samples for different particle sizes for the clay-cow pie ratio 9:6:5 at levels of significance α=0.01 and α=0.05. The overall specific heat capacity at confidence level α=0.01 and α=0.05 was affected by the particle sizes of the clays.

4.4.3 Specific heat capacity of the samples for the ratio 9:7:0

The third clay: cow pie ratio considered was 9:7:0 and samples were labeled E1 to E5. The average specific heat capacity values of each of the samples for clay particle sizes of 0-74 µm labelled E1, 75-89 µm labelled E2, 90-149 µm labelled E3, 150-299 µm labelled E4 and 300-349 µm labelled E5 obtained for this ratio are given in Table 4.39.

Table 4.39: Average specific heat capacity values, standard deviation and maximum error estimate for the ratio 9:7:0

SAMPLES	**E5**	**E4**	**E3**	**E2**	**E1**
specific heat capacity ($Jg^{-1}\,{}^{0}C^{-1}$)	1.0690	1.0490	1.0460	1.0200	1.0510
STD ($Jg^{-1}\,{}^{0}C^{-1}$)	0.0140	0.0160	0.0090	0.0130	0.0520
Max Error ($Jg^{-1}\,{}^{0}C^{-1}$) α=0.01	0.1078	0.0270	0.0188	0.0323	0.0293
α=0.05	0.0650	0.0163	0.0113	0.0195	0.0177

To compare the specific heat capacities for the different particle sizes, a bar chart of specific heat capacity against particle sizes was drawn as shown in Figure 4.19.

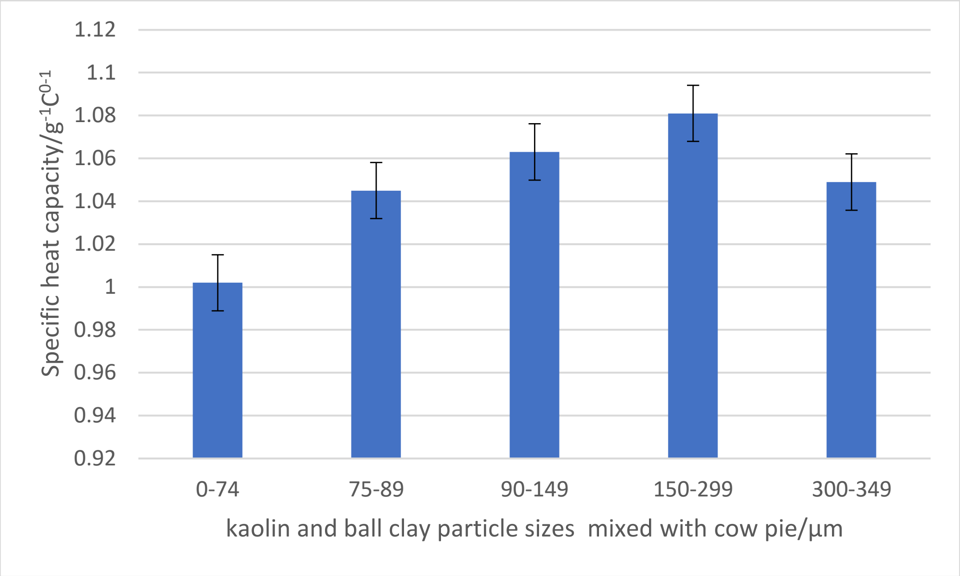

Figure 4.19: A bar chart of specific heat capacity against particle size of kaolin, ball clay mixed with cow pie in the ratio of 9:7:0

From Figure 4.19, the specific heat capacity values are different for different particle sizes of samples for the clay-cow pie ratio 9:7:0. The lowest specific heat capacity values were $1.020 \pm 0.0323\ Jg^{-1}\,{}^{0}C^{-1}$ and the highest specific heat capacity values were $1.0690 \pm 0.1078\ Jg^{-1}\,{}^{0}C^{-1}$ for the level of significance α=0.01 and lowest specific heat capacity values were $1.020 \pm 0.0195\ Jg^{-1}\,{}^{0}C^{-1}$ and the highest specific heat capacity values were $1.0690 \pm 0.0650\ Jg^{-1}\,{}^{0}C^{-1}$ for level of significance α=0.05 respectively.

To test if the differences of the specific heat capacity for the different particle sizes were statistically significant, the F-value was determined for the five different mean specific heat capacities at levels of significant α=0.01 and α=0.05 as indicated in Table 4.40.

Table 4.40: F-value calculated and the p-value for specific heat capacity for the ratio 9:7:0

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**	**p-value at α=0.01**	**p-value at α=0.05**
2.2000	4.4300	2.8700	0.0100	0.0498

From Table 4.40, the calculated F-value is lower than the critical value obtained from the F-distribution Table, then, the hypothesis is accepted because there is no significant difference between the values of specific heat capacity of the samples for different particle sizes for the clay-cow pie ratio 9:7:0. The overall specific heat capacity calculated for all the 25 samples was 1.0471 ± 0.1794 $Jg^{-1}\,{}^{0}C^{-1}$ and 1.0471±0.1081 $Jg^{-1}\,{}^{0}C^{-1}$ at levels of significance α=0.01 and α=0.05 respectively. There was no significant difference between the values of specific heat capacities of the samples and the overall specific heat capacities for this mixture ratio at limit of error at α=0.01 and α=0.05 confidence levels.

Also, from Table 4.40, the calculated p-value is equal to the level of significance α=0.01. This is because there is too much variability for the hypothesis to detect but the calculated p-value is less than the level of significance α=0.05, therefore, the hypothesis is finally rejected.

4.4.4 Specific heat capacity for particle size 0 - 74 µm

This set of result was to determine how specific heat capacity of each particle size varied with the clay-cow pie ratios.

The first result was to find the mean specific heat capacity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The specific heat capacity values of each of the samples of clay-cow pie particle size of 0 - 74 µm for all the three ratios were obtained and recorded as shown in Table 4.41.

Table 4.41: Average specific heat capacity, standard deviation and maximum error estimate of particle size of 0 - 74 μm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
Specific heat capacity ($Jg^{-1}\,{}^{0}C^{-1}$)		1.0100	1.0020	1.0510
STDV ($Jg^{-1}\,{}^{0}C^{-1}$)		0.0060	0.0090	0.0520
Max Error ($Jg^{-1}\,{}^{0}C^{-1}$)	**α=0.01**	0.0119	0.0185	0.1078
	α=0.05	0.0072	0.0111	0.0650

To compare the specific heat capacity for the different ratios, a bar chart of specific heat capacity against clay-cow pie ratios was drawn as shown in Figure 4.20.

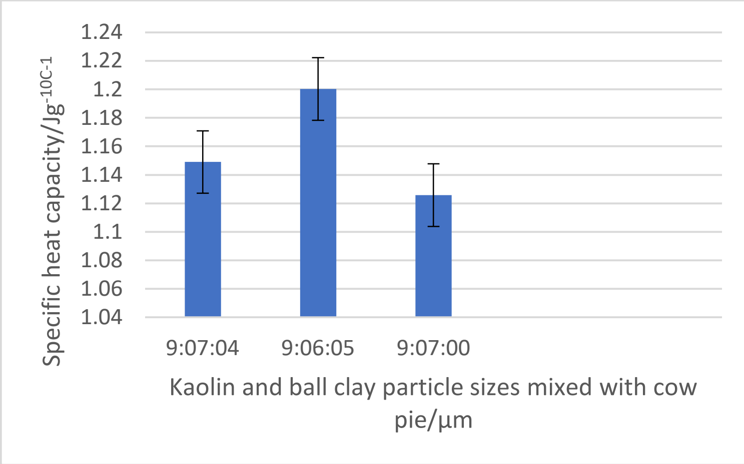

Figure 4.20: A bar chart of specific heat capacity against clay- cow pie ratios

The bar chart in Figure 4.20 shows that the specific heat capacity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the specific heat capacity for the different ratios were statistically significant, the F-value was determined for the mean specific heat capacity at levels of significant α=0.01 and α=0.05 as shown in Table 4.42.

Table 4.42: F-ratio calculated values for specific heat capacity for particle size 0-74 μm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
15.6500	6.9300	3.8900

From Table 4.42, the calculated F-value is greater than the critical value obtained from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference

between the values of density of the samples for the clay-cow pie mixture ratios of 9:7:4 ,9:6:5 and 9:7:0 at both level of significance of α=0.01 and α=0.05.

4.4.5 Specific heat capacity for particle size 75-89 µm

The second result was to find the mean specific heat capacity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The specific heat capacity values of each of the samples of clay -cow pie particle size of 75-89 µm for all the three ratios were obtained and recorded as shown in Table 4.43.

Table 4.43: Average specific heat capacity, standard deviation and maximum error estimate of particle size of 75-89 µm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
Specific heat capacity ($Jg^{-1}\,{}^{0}C^{-1}$)		1.049	1.067	1.020
STDV ($Jg^{-1}\,{}^{0}C^{-1}$)		0.023	0.009	0.013
Max Error ($Jg^{-1}\,{}^{0}C^{-1}$)	**α=0.01**	0.0480	0.0189	0.0270
	α=0.05	0.0290	0.0114	0.0163

To compare the specific heat capacity for the different ratios, a bar chart of specific heat capacity against clay-cow pie ratios was drawn as shown in Figure 4.21.

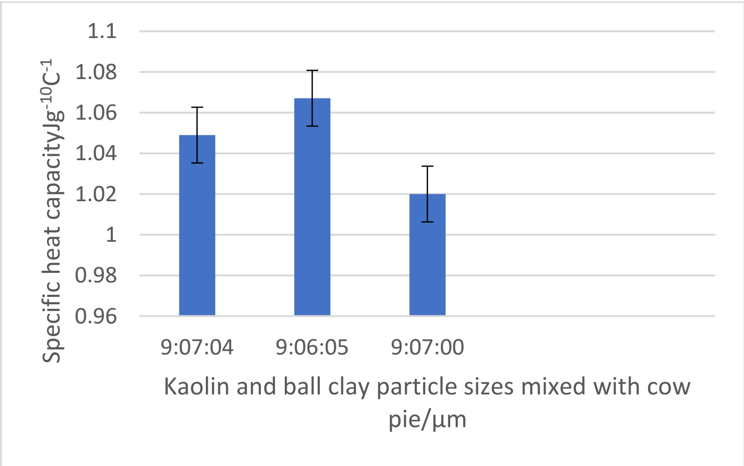

Figure 4.21: A bar chart of specific heat capacity against clay- cow pie ratios

The bar chart in Figure 4.21 shows that the specific heat capacity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the specific heat capacity for the different ratios were statistically significant, the F- value was determined for the mean specific heat capacity at levels of significant α=0.01 and α=0.05 as shown in Table 4.44.

Table 4.44: F-ratio calculated values for specific heat capacity for particle size 75-89 µm

F- value calculated	F-value critical α=0.01	F-critical value at α=0.05
13.8000	6.9300	3.8900

From Table 4.44, the calculated F-value is greater than the critical value from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of density of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at both level of significance of α=0.01 and α=0.05.

4.4.6 Specific heat capacity for particle size 90-149 µm

The third result was to find the mean specific heat capacity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The specific heat capacity values of each of the samples of clay-cow pie particle size of 90-149 µm for all the three ratios were obtained and recorded as shown in Table 4.45.

Table 4.45: Average specific heat capacity, standard deviation and maximum error estimate of particle size of 90-149 µm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		9:7:4	9:6:5	9:7:0
Specific heat capacity ($Jg^{-1}\,^0C^{-1}$)		0.981	1.063	1.067
STDV ($Jg^{-1}\,^0C^{-1}$)		0.014	0.019	0.0091
Max Error ($Jg^{-1}\,^0C^{-1}$)	α=0.01	0.0291	0.0384	0.0189
	α=0.05	0.0176	0.0231	0.0114

To compare the specific heat capacity for the different ratios, a bar chart of specific heat capacity against clay-cow pie ratios was drawn as shown in Figure 4.22.

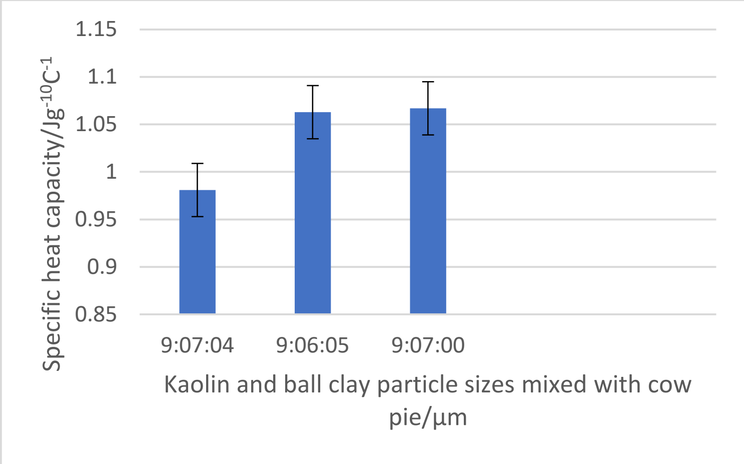

Figure 4.22: A bar chart of specific heat capacity against clay- cow pie ratios

The bar chart in Figure 4.22 shows that the specific heat capacity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the specific heat capacity for the different ratios were statistically significant, the F- value was determined for the mean specific heat capacity at levels of significant α=0.01 and α=0.05 as shown in Table 4.46.

Table 4.46: F-ratio calculated values for specific heat capacity for particle size 90-149 µm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**	**p-value α=0.01**
6.8000	6.9300	3.8900	0.0276

From Table 4.46, the calculated F-value is less than the critical value obtained from the F-distribution Table, then, the hypothesis is accepted because there is no significant difference between the values of specific heat capacity of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at level of significance of α=0.01. The overall specific heat capacity at level of significance α=0.01 was 5.1500 ± 0.0970 $Jg^{-1}\,^{0}C^{-1}$.

Also, from Table 4.46, the calculated p-value is greater than the level of significance α=0.01 but this does not mean that the hypothesis is accepted. Also, if the p-value is greater than the level of significance but less than 0.05 (0.05 is taken to be the level of power for medium effect size at which most behavioral scientists work, Cohen, (1962)). Also, it is at 0.05 where type 11 errors happen. Furthermore, in a study by Cohen, (1994), he noted that the null hypothesis is always false, in other words the null hypothesis at α=0.01 is rejected. Also, such a relationship in the samples only reflects an error and that informally, the null hypothesis "occurred by chance" (Chiang, 2015). In an attempt to explain how low a p-value should be, Chiang, (2015) says that if there is a 5% chance of an outcome as extreme as the sample, then the null hypothesis is rejected and the results are considered to be statistically significant. However, at the level of significance of α=0.05, the calculated F-value is greater than the critical value from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of density of the samples for the clay-cow pie mixture ratios of 9:7:4 ,9:6:5 and 9:7:0.

4.4.7 Specific heat capacity for particle size 150-299 µm

The fourth result was to find the mean specific heat capacity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The specific heat capacity values of each of the samples of clay-cow pie particle size of 150-299 µm for all the three ratios were obtained and recorded as shown in Table 4.47.

Table 4.47: Average specific heat capacity, standard deviation and maximum error estimate of particle size of 150-299 µm for the ratio 9:7:4, 9:6:5 and 9:7:0.

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
Specific heat capacity ($Jg^{-1}{}^{0}C^{-1}$)		1.0510	1.0670	1.0490
STDV ($Jg^{-1}{}^{0}C^{-1}$)		0.0110	0.0091	0.0160
Max Error ($Jg^{-1}{}^{0}C^{-1}$)	**α=0.01**	0.0226	0.0189	0.0323
	α=0.05	0.0136	0.0114	0.0195

To compare the specific heat capacity for the different ratios, a bar chart of specific heat capacity against clay-cow pie ratios was drawn as shown in Figure 4.24.

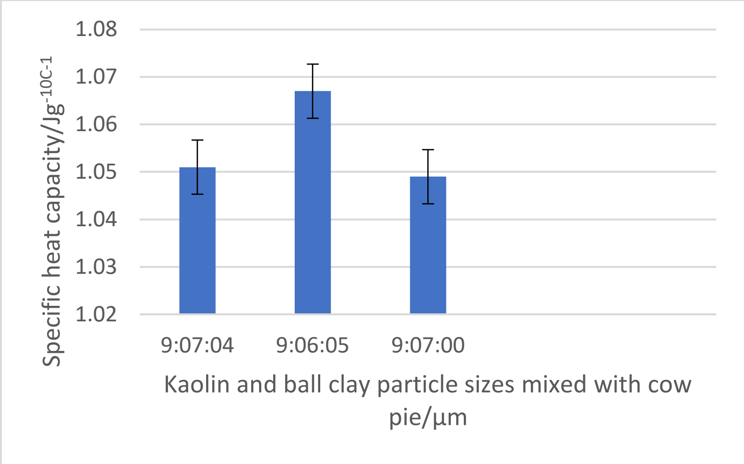

Figure 4.24: A bar chart of specific heat capacity against clay- cow pie ratios

The bar chart in Figure 4.24 shows that the specific heat capacity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the specific heat capacity for the different ratios were statistically significant, the F- value was determined for the mean specific heat capacity at levels of significant α=0.01 and α=0.05 as shown in Table 4.48.

Table 4.48: F-ratio calculated values for specific heat capacity for particle size 150-299 µm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
9.2500	6.9300	3.8900

From Table 4.48, the calculated F-value is greater than the critical value from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of specific heat capacity of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at both levels of significance of α=0.01 and α=0.05.

4.4.8 Specific heat capacity for particle size 300 - 349 µm

The fifth result was to find the mean specific heat capacity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The specific heat capacity values of each of the samples of clay-cow pie particle size of 300-349 µm for all the three ratios were obtained and recorded as shown in Table 4.49.

Table 4.49: Average specific heat capacity, standard deviation and maximum error estimate of particle size of 300 - 349 μm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio	**9:7:4**	**9:6:5**	**9:7:0**
Specific heat capacity ($Jg^{-10}C^{-1}$)	1.0670	1.0490	1.0690
STDV ($Jg^{-10}C^{-1}$)	0.0090	0.0170	0.0140
Max Error ($Jg^{-10}C^{-1}$ α=0.01	0.0189	0.0342	0.0293
α=0.05	0.0114	0.0206	0.0177

To compare the specific heat capacity for the different ratios, a bar chart of specific heat capacity against clay-cow pie ratios was drawn as shown in Figure 4.25.

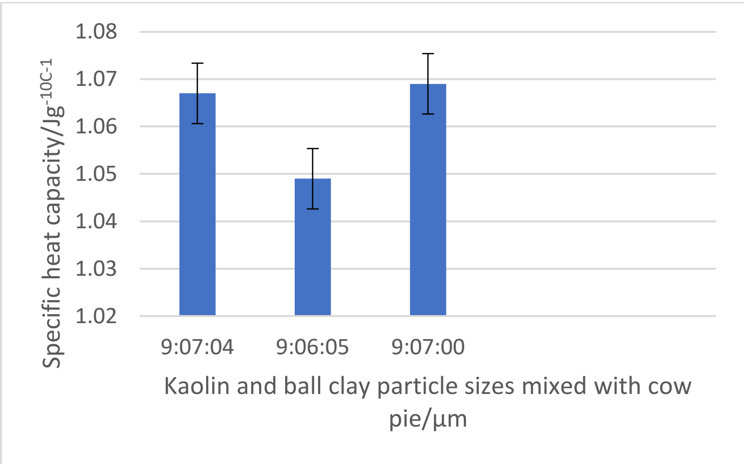

Figure 4.25: A bar chart of specific heat capacity against clay- cow pie ratios

The bar chart in Figure 4.25 shows that the specific heat capacity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the specific heat capacity for the different ratios were statistically significant, the F-value was determined for the mean specific heat capacity at levels of significant α=0.01 and α=0.05 as shown in Table 4.50.

Table 4.50: F-ratio calculated values for specific heat capacity for particle size 300-349 μm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
17.4900	6.9300	3.8900

From Table 4.50, the calculated F-value is greater than the critical value obtained from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference

between the values of density of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at both level of significance of α=0.01 and α=0.05.

4.4.9 Conclusion on the effect of particle size on specific heat capacity

Table 4.51: Summary of the decision made on the null hypothesis, H_{O3} set in Section 1.

Clay-cow pie ratio/particle size	Decision on the null hypothesis
9:7:4	Rejected
9:6:5	Rejected
9:7:0	Rejected
0-74	Rejected
75-89	Rejected
90-149	Rejected
150-299	Rejected
300-349	Rejected

4.4.9.1 Effect of particle size on specific heat capacity

Reducing particle sizes of kaolin and ball clay generally changed the specific heat capacity. The effect of particle size of kaolin clay and ball clay on specific heat capacity was attributed to the amount of heat held by a body and also a reduction in the voids left in the clay matrix.

4.4.9.2 Effect of change of ratio on specific heat capacity

There was a statistically significant difference between the values of specific heat capacity of the samples for different particle sizes at level of significances α =0.01 and also it was noted that at α =0.05, there was a statistically significant difference between the values of specific heat capacity for the different clay-cow pie ratios.

Increasing the percentage of cow pie resulted into an increase in the voids left after firing the clay sample hence changing the specific heat capacity.

In the absence of a pore former, specific heat capacity increased due to the absence of voids.

4.5.0 Thermal diffusivity values

The fourth objective of this study was to calculate thermal diffusivity values of the samples produced from five different particle sizes 0-74, 75-89, 90-149, 150-299 and 300-349 μm of three clays: cow pie ratios.

4.5.1 Thermal diffusivity values for the ratio 9:7:4

The first clay: cow pie ratio considered was 9:7:4 and samples were labeled A1 to A5. The average thermal diffusivity values of each of the samples for clay particle sizes of 0-74 μm labelled A1, 75-89 μm labelled A2, 90-149 μm labelled A3, 150-299 μm labelled A4 and 300-349 μm labelled A5 obtained for this ratio are given in Table 4.52.

Table 4.52: Average thermal diffusivity (D), standard deviation (σ_1) and maximum error estimate (σ_{M1}) for the ratio 9:7:4

SAMPLES	**A1**	**A2**	**A3**	**A4**	**A5**
$D\ e^{-6}\ (m^2 s^{-1})$	0.2039	0.2441	0.1883	0.2021	0.1924
$\sigma_1\ e^{-6}\ (m^2 s^{-1})$	0.0026	0.0080	0.0058	0.0174	0.0030
$\sigma_{M1}\ e^{-6}$ α=0.01	0.0053	0.0165	0.0120	0.0358	0.0063
α=0.05	0.0032	0.0099	0.0072	0.0216	0.0038

To compare the thermal diffusivities for the different particle sizes, a bar chart of thermal diffusivity against particle sizes was drawn as shown in Figure 4.26.

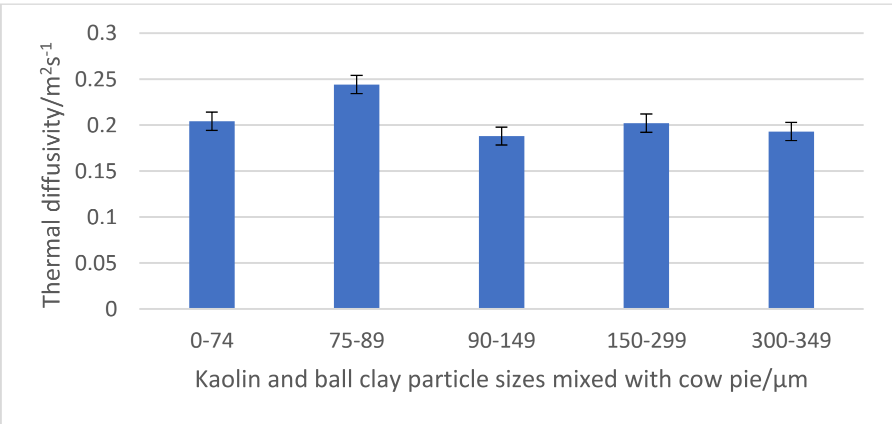

Figure 4.26: A bar chart of thermal diffusivity against particle size of kaolin, ball clay mixed with cow pie in the ratio of 9:7:4

Figure 4.26 shows that thermal diffusivity values are different for different particle sizes for the clay-cow pie ratio 9:7:4. The lowest thermal diffusivity values obtained were $0.188 \pm 0.0120 e^{-6}$ m^{2} s^{-1} and the highest thermal diffusivity values were $0.2440 \pm 0.0165 e^{-6}$ m^{2}s^{-1} at level of significance α=0.01 and lowest thermal diffusivity values were $0.1880 \pm 0.0072 e^{-6}$ m^{2}s^{-1} while the highest thermal diffusivity values were $0.2440 \pm 0.0099 e^{-6}$ m^{2}s^{-1}at level of significance α=0.05.

To test if the differences of the thermal diffusivity for the different particle sizes were statistically significant, the F-value was determined for the five different mean thermal diffusivities at levels of significance α=0.01 and α=0.05 as indicated in Table 4.53.

Table 4.53: F-value calculated for thermal diffusivity for clay-cow pie ratio 9:7:4

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
29.6	4.43	2.87

From Table 4.53, the calculated F-value is greater than the critical value obtained from the F-distribution then, the hypothesis is rejected because there is a significant difference between the values of thermal diffusivity of the samples for different particle sizes for the clay-cow pie ratio 9:7:4.

4.5.2 Thermal diffusivity values for the ratio 9:6:5

The second clay: cow pie ratio considered was 9:6:5 and samples were labeled D1 to D5. The average values of each of the samples for clay particle sizes of 0-74 µm labelled D1, 75-89 µm labelled D2, 90-149 µm labelled D3, 150-299 µm labelled D4 and 300-349 µm labelled D5 obtained for this ratio are given in Table 4.54.

Table 4.54: Average thermal diffusivity (D), standard deviation (σ_{1}) and maximum error estimate (σ_{M1}) for the ratio 9:6:5

SAMPLES		**D1**	**D2**	**D3**	**D4**	**D5**
D e^{-6} (m^{2} s^{-1})		0.2031	0.2080	0.2046	0.2005	0.1919
$\sigma_{1} e^{-6}$ (m^{2} s^{-1})		0.0034	0.0025	0.0068	0.0084	0.0086
$\sigma_{M1} e^{-6}$ (m^{2}s^{-1})	**α = 0.01**	0.0070	0.0051	0.0141	0.0173	0.0176
	α=0.05	0.0042	0.0031	0.0085	0.0104	0.0106

To compare the thermal diffusivities for the different particle sizes, a bar chart of thermal diffusivity against particle sizes was drawn as shown in Figure 4.27.

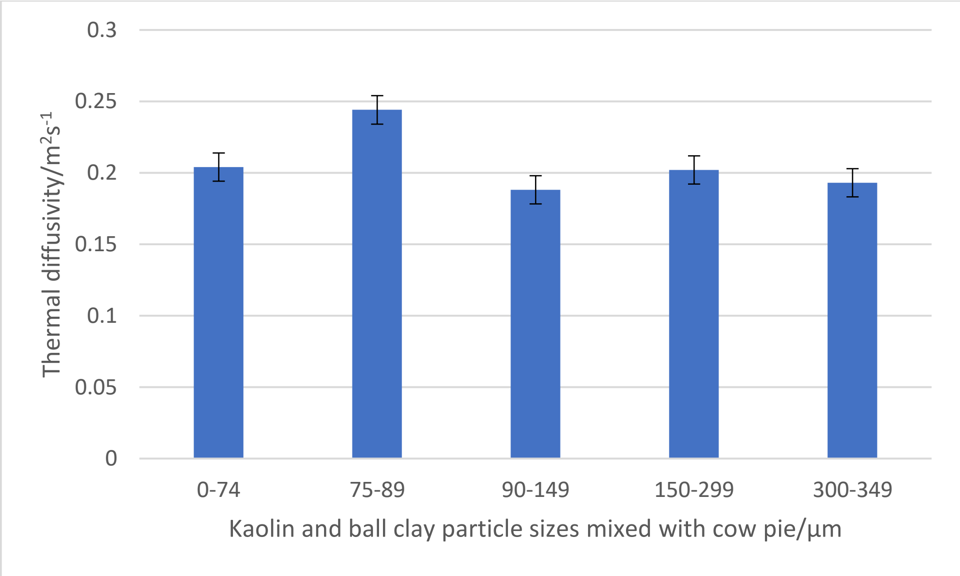

Figure 4.27: A bar chart of thermal diffusivity against particle size of kaolin, ball clay mixed with cow pie in the ratio of 9:6:5

From Figure 4.27, thermal diffusivity values are different for different particle sizes of samples for the clay-cow pie ratio 9:6:5. The lowest thermal diffusivity values obtained were 0.1920 ± 0.0176 e^{-6} m^2 s^{-1} and the highest thermal diffusivity values obtained from Figure 4.27 were 0.2080 ± 0.0051 e^{-6} m^2 s^{-1} at level of significance α=0.01 and lowest thermal diffusivity values were 0.1920 ± 0.0106 e^{-6} m^2 s^{-1} while the highest thermal diffusivity values were 0.2080 ± 0.0031 e^{-6} m^2s^{-1} at level of significance α=0.05.

To test if the differences of the thermal diffusivity for the different particle sizes were statistically significant, the F-value was determined for the five different mean thermal diffusivities at levels of significant α=0.01 and α=0.05 as shown in Table 4.55 in the appendix section.

Table 4.55: F-value calculated for thermal diffusivity for clay-cow pie ratio 9:6:5

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
4.4600	4.4300	2.8700

Also from Table 4.55, the calculated F-value is greater than the critical value obtained from the F-distribution then, the hypothesis is rejected because there is a significant difference between the values of thermal diffusivity of the samples for different particle sizes for the clay-cow pie ratio 9:6:5 at levels of significance α=0.01 and α=0.05.

4.5.3 Thermal diffusivity values for the ratio 9:7:0

The third clay: cow pie ratio considered was 9:7:0 and samples were labeled E1 to E5. The average thermal diffusivity values of each of the samples for clay particle sizes of 0-74 µm labelled E1, 75-89 µm labelled E2, 90-149 µm labelled E3, 150-299 µm labelled E4 and 300-349 µm labelled E5 are given in Table 4.56

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Table 4.56: Average Thermal diffusivity (D), standard deviation (σ_1) and maximum error estimate (σ_{M1}) for the ratio 9:7:0

SAMPLES		E1	E2	E3	E4	E5
$D\ e^{-6}$ ($m^2 s^{-1}$)		0.2550	0.2440	0.2427	0.2470	0.2250
$\sigma_1\ e^{-6}$ ($m^2 s^{-1}$)		0.0186	0.0172	0.0113	0.0070	0.0320
$\sigma_{M1}\ e^{-6}$ ($m^2 s^{-1}$)	**α=0.01**	0.0383	0.0354	0.0232	0.0146	0.0664
	α=0.05	0.0231	0.0214	0.0140	0.0088	0.0400

To compare the thermal diffusivities for the different particle sizes, a bar chart of thermal diffusivity against particle sizes was drawn as shown in Figure 4.28.

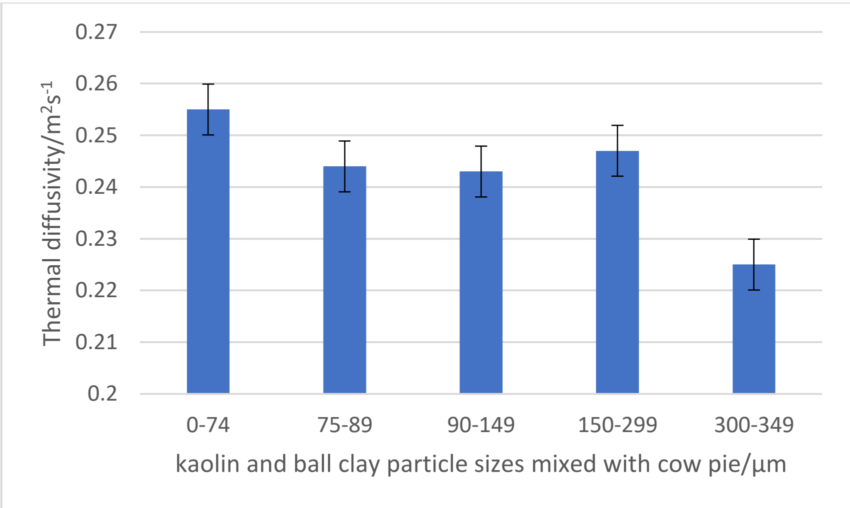

Figure 4.28: A bar chart of thermal diffusivity against particle size of kaolin, ball clay mixed with cow pie in the ratio of 9:7:0

From Figure 4.28, thermal diffusivity values are different for different particle size of samples for the clay-cow pie ratio 9:7:0. The lowest thermal diffusivity values obtained were

0.2250 ± 0.0664 e^{-6} m^2 s^{-1} while the highest thermal diffusivity values read from Figure 4.28 were 0.2550 ± 0.0383 e^{--6} m^2 s^{-1} at level of significance α=0.01 and the lowest thermal diffusivity values were 0.2250 ± 0.0400 e^{-6} m^2 s^{-1} and while the highest thermal diffusivity values were 0.2550 ± 0.0231 e^{--6} m^2 s^{-1} at α = 0.05.

To test if the differences of the thermal diffusivity for the different particle sizes were statistically significant, the F- value was determined for the five different mean thermal diffusivities at levels of significance α = 0.01 and α = 0.05 as shown in Table 4.57.

Table 4.57: F-value calculated for thermal diffusivity for clay-cow pie ratio 9:7:0

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**	**p-value at α=0.01**	**p-value at α=0.05**
1.5400	4.4300	2.8700	0.0100	0.0487

From Table 4.57, the calculated F-value is lower than the critical values obtained from the F-distribution Table then, the hypothesis is accepted because there is no significant difference between the values of thermal diffusivity of the samples for different particle sizes for the clay-cow pie ratio 9:7:0. The overall thermal diffusivity calculated for all the samples was 0.2426 ± 0.110 e^{-6} m^2s^{-1} and 0.2426 ± 0.0664 e^{-6} m^2s^{-1} at both levels of significance α = 0.01 and α = 0.05. There was no significant difference between the values of thermal diffusivity of the samples.

Also, from Table 4.57, the calculated p-value is equal to the level of significance α=0.01. This is because there is too much variability for the hypothesis to detect but the calculated p-value is less than the level of significance α=0.05, therefore, the hypothesis was finally rejected.

4.5.4 Thermal diffusivity for particle size 0 - 74 µm

This set of results was to determine how thermal diffusivity of each particle size varied with the clay-cow pie ratios.

The first result was to find the mean thermal diffusivity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The thermal diffusivity values of each of the samples of clay-cow pie particle size of 0 - 74 µm for all the three ratios were obtained and recorded as shown in Table 4.58.

Table 4.58: Average Thermal diffusivity, standard deviation and maximum error estimate of particle size of 0 - 74 µm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
$D_e{}^{-6}$(m^2s^{-1})		0.1924	0.1919	0.2546
$\sigma_{1e}{}^{--6}$(m^2s^{-1})		0.0026	0.0034	0.0186
$\sigma_{M1e}{}^{--6}$(m^2s^{-1})	**α=0.01**	0.0053	0.0070	0.0383
	α=0.05	0.0032	0.0042	0.0231

To compare the thermal diffusivity for the different ratios, a bar chart of thermal diffusivity against clay-cow pie ratios was drawn as shown in Figure 4.29.

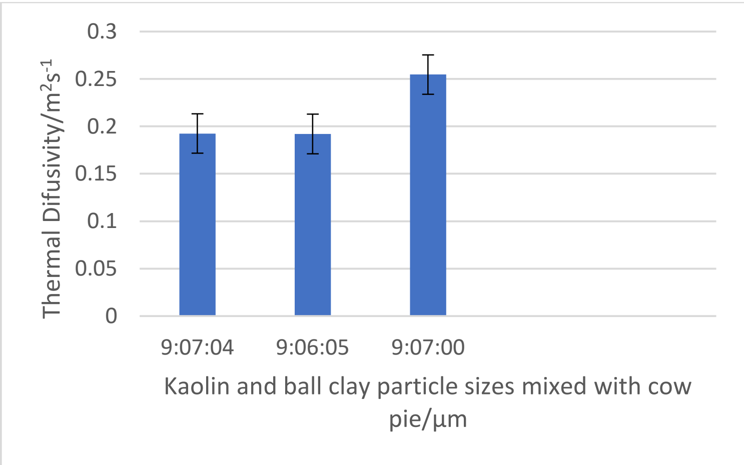

Figure 4.29: A bar chart of thermal diffusivity against clay- cow pie ratios

The bar chart in Figure 4.29 shows that the thermal diffusivity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different. To test if the differences of the thermal diffusivity for the different ratios were statistically significant, the F- value was determined for the mean thermal diffusivity at levels of significant α=0.01 and α=0.05 as shown in Table 4.59.

Table 4.59: F-ratio calculated values for thermal diffusivity for particle size 0-74 μm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**	**p-value at α=0.01**
6.6700	6.9300	3.8900	0.0276

From Table 4.59, the calculated F-value is less than the critical value obtained from the F-distribution Table, then, the hypothesis is accepted because there is no significant difference between the values of thermal diffusivity of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at level of significance of α=0.01. The overall thermal diffusivity at level of significance α=0.01 was 1.0650± 0.0186 e^{-6} m^2s^{-1}.
Also, from Table 4.59, the calculated p-value is greater than the level of significance α=0.01 but this does not mean that the hypothesis is accepted. Also, if the p-value is greater than the level of significance but less than 0.05 (0.05 is taken to be the level of power for medium effect size at which most behavioral scientists work, Cohen, (1962)). Also, it is at 0.05 where type 11 errors happen. Furthermore, in a study by Cohen, (1994), he noted that the null hypothesis is always false, in other words the null hypothesis at α=0.01 is rejected. Also, such a relationship in the samples only reflects an error and that informally, the null hypothesis "occurred by chance" (Chiang, 2015). In an attempt to explain how low a p-value should be, Chiang, (2015) says that if there is a 5% chance of an outcome as extreme as the sample, then the null hypothesis is rejected and the results are considered to be statistically significant.

However, at the level of significance of α=0.05, the calculated F-value is greater than the critical value from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of thermal diffusivity of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0.

4.5.5 Thermal diffusivity for particle size 75 - 89 μm

The second result was to find the mean thermal diffusivity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The thermal diffusivity values of each of the samples of clay-cow pie particle size of 75-89 μm for all the three ratios were obtained and recorded as shown in Table 4.60.

Table 4.60: Average thermal diffusivity, standard deviation and maximum error estimate of particle size of 75 - 89 µm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
$\mathbf{D}_e$ $^{-6}$ $(\mathbf{m^2s^{-1}})$		0.2021	0.2004	0.2439
σ_{1e} $^{-6}$ $(\mathbf{m^2s^{-1}})$		0.0080	0.0025	0.0172
σ_{M1e} $^{-6}$ $(\mathbf{m^2s^{-1}})$	**α=0.01**	0.0165	0.0051	0.0354
	α=0.05	0.0099	0.0031	0.0214

To compare the thermal diffusivity for the different ratios, a bar chart of thermal diffusivity against clay-cow pie ratios was drawn as shown in Figure 4.30.

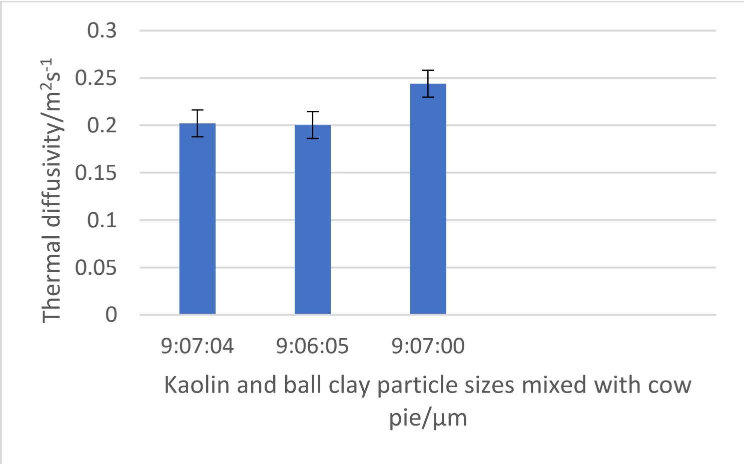

Figure 4.30: A bar chart of thermal diffusivity against clay- cow pie ratios

The bar chart in Figure 4.30 shows that the thermal diffusivity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different. To test if the differences of the thermal diffusivity for the different ratios were statistically significant, the F- value was determined for the mean thermal diffusivity at levels of significant α=0.01 and α=0.05 as shown in Table 4.61.

Table 4.61: F-ratio calculated values for thermal diffusivity for particle size 75-89 µm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
7.4500	6.9300	3.8900

From Table 4.61, the calculated F-value is greater than the critical value obtained from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference

between the values of thermal diffusivity of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at both levels of significance of α=0.01 and α=0.05.

4.5.6 Thermal diffusivity for particle size 90 - 149 μm

The third result was to find the mean thermal diffusivity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The thermal diffusivity values of each of the samples of clay-cow pie particle size of 90 - 149 μm for all the three ratios were obtained and recorded as shown in Table 4.62.

Table 4.62: Average thermal diffusivity, standard deviation and maximum error estimate of particle size of 90 - 149 μm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
$D\,e^{-6}(m^2s^{-1})$		0.1883	0.2046	0.2427
$\sigma_1\,e^{-6}(m^2\,s^{-1})$		0.0058	0.0068	0.0113
$\sigma_{M1}\,e^{-6}\,(m^2\,s^{-1})$	**α=0.01**	0.0120	0.0141	0.0232
	α=0.05	0.0072	0.0085	0.0140

To compare the thermal diffusivity for the different ratios, a bar chart of thermal diffusivity against clay-cow pie ratios was drawn as shown in Figure 4.31.

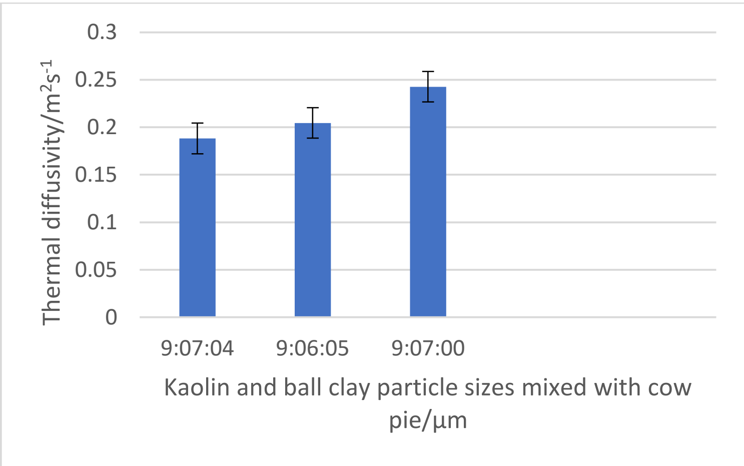

Figure 4.31: A bar chart of thermal diffusivity against clay- cow pie ratios

The bar chart in Figure 4.31 shows that the thermal diffusivity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the thermal diffusivity for the different ratios were statistically significant, the F- value was determined for the mean thermal diffusivity at levels of significant α=0.01 and α=0.05 as shown in Table 4.63.

Table 4.63: F-ratio calculated values and p-value for thermal diffusivity for particle size 90-149 µm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**	**p-value at α=0.01**
6.6400	6.9300	3.8900	0.0276

From Table 4.63, the calculated F-value is less than the critical value obtained from the F-distribution Table, then, the hypothesis is accepted because there is no significant difference between the values of thermal diffusivity of the samples for the clay-cow pie mixture ratios of 9:7: 4, 9:6:5 and 9:7:0 at level of significance of α=0.01. The overall thermal diffusivity at level of significance α=0.01 was 1.059 ± 0.006 x e^{-6} $m^2 s^{-1}$.

Also, from Table 4.63, the calculated p-value is greater than the level of significant but this does not mean that the hypothesis is accepted. Also, if the p-value is greater than the level of significance but less than 0.05 (0.05 is taken to be the level of power for medium effect size at which most behavioral scientists work, Cohen, (1962)). Also, it is at 0.05 where type 11 errors happen. Furthermore, in a study by Cohen, (1994), he noted that the null hypothesis is always false, in other words the null hypothesis at α=0.01 is rejected. Also, such a relationship in the samples only reflects an error and that informally, the null hypothesis "occurred by chance" (Chiang, 2015). In an attempt to explain how low a p-value should be, Chiang, (2015) says that if there is a 5% chance of an outcome as extreme as the sample, then the null hypothesis is rejected and the results are considered to be statistically significant.

However, at the level of significance of α=0.05, the calculated F-value is greater than the critical value from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of thermal diffusivity of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0.

4.5.7 Thermal diffusivity for particle size 150 - 299 µm

The fourth result was to find the mean Thermal diffusivity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0. The thermal diffusivity values of each of the samples of clay-cow pie particle size of 150 - 299 µm for all the three ratios were obtained and recorded as shown in Table 4.64.

Table 4.64: Average thermal diffusivity, standard deviation and maximum error estimate of particle size of 150 - 299 µm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
D_e^{-6} ($m^2 s^{-1}$)		0.2441	0.2080	0.2466
σ_{1e}^{-6} ($m^2 s^{-1}$)		0.0174	0.0084	0.0071
σ_{M1e}^{-6} ($m^2 s^{-1}$)	**α=0.01**	0.0358	0.0173	0.0146
	α=0.05	0.0216	0.0104	0.0088

To compare the thermal diffusivity for the different ratios, a bar chart of thermal diffusivity against clay-cow pie ratios was drawn as shown in Figure 4.32.

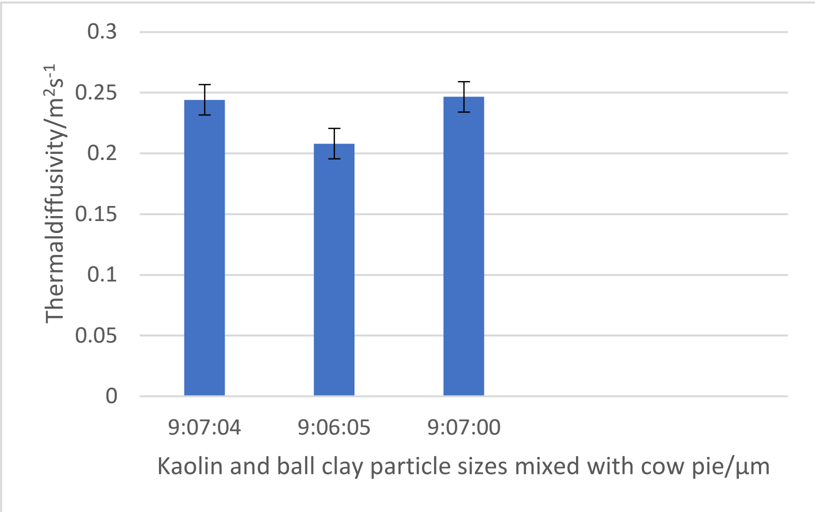

Figure 4.32: A bar chart of thermal diffusivity against clay-cow pie ratios

The bar chart in Figure 4.32 shows that the thermal diffusivity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the thermal diffusivity for the different ratios were statistically significant, the F- value was determined for the mean thermal diffusivity at levels of significant α=0.01 and α=0.05 as shown in Table 4.65.

Table 4.65: F-ratio calculated values for thermal diffusivity for particle size 150-299 µm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
7.4500	6.9300	3.8900

From Table 4.65, the calculated F-value is greater than the critical value from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of thermal diffusivity of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at both levels of significance of α=0.01 and α=0.05.

4.5.8 Thermal diffusivity for particle size 300 - 349 μm

The fifth result was to find the mean thermal diffusivity of samples produced using kaolin rich clay, ball clay and cow pie in the ratio of 9:7:4, 9:6:5 and 9:7:0.

The thermal diffusivity values of each of the samples of clay-cow pie particle size of 300 - 349 μm for all the three ratios were obtained and recorded as shown in Table 4.66.

Table 4.66: Average thermal diffusivity, standard deviation and maximum error estimate of particle size of 300 - 349 μm for the ratio 9:7:4, 9:6:5 and 9:7:0

Ratio		**9:7:4**	**9:6:5**	**9:7:0**
$D\,e^{-6}$ ($m^2 s^{-1}$)		0.2039	0.2031	0.2254
$\sigma_1\,e^{-6}$ ($m^2 s^{-1}$)		0.0031	0.0086	0.0323
$\sigma_{M1}\,e^{-6}$ ($m^2 s^{-1}$)	**α=0.01**	0.0063	0.0176	0.0664
	α=0.05	0.0038	0.0106	0.0400

To compare the thermal diffusivity for the different ratios, a bar chart of thermal diffusivity against clay-cow pie ratios was drawn as shown in Figure 4.33.

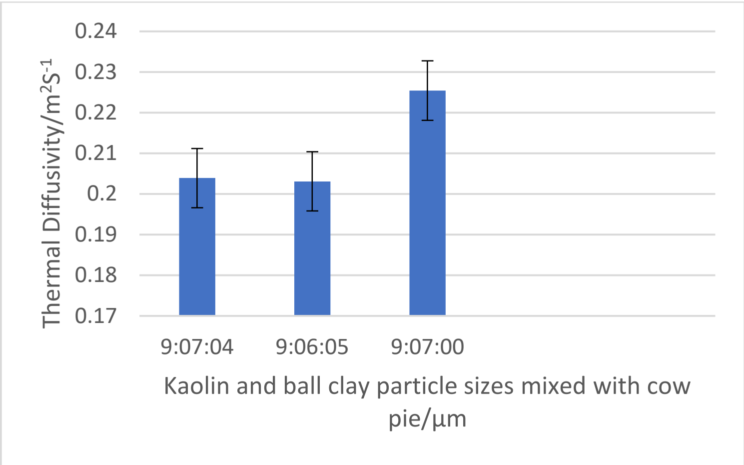

Figure 4.33: A bar chart of thermal diffusivity against clay- cow pie ratios

The bar chart in Figure 4.33 shows that the thermal diffusivity values of the samples for these mixture ratios 9:7:4, 9:6:5 and 9:7:0 were different.

To test if the differences of the thermal diffusivity for the different ratios were statistically significant, the F- value was determined for the mean thermal diffusivity at levels of significant α=0.01 and α=0.05 as shown in Table 4.67.

Table 4.67: F-ratio calculated values for thermal diffusivity for particle size 300-349 µm

F- value calculated	**F-value critical α=0.01**	**F-critical value at α=0.05**
22.8400	6.9300	3.8900

From Table 4.67, the calculated F-value is greater than the critical value obtained from the F-distribution Table, then, the hypothesis is rejected because there is a significant difference between the values of thermal diffusivity of the samples for the clay-cow pie mixture ratios of 9:7:4, 9:6:5 and 9:7:0 at both levels of significance of α=0.01 and α=0.05.

4.5.9 Summary on the effect of particle size and mixture ration on thermal diffusivity

Table 4.68: Summary of the decision made on the null hypothesis, H_{04} set in Section 1.

Clay-cow pie ratio/particle size	**Decision on the null hypothesis**
9:7:4	Rejected
9:6:5	Rejected
9:7:0	Rejected
0-74	Rejected
75-89	Rejected
90-149	Rejected
150-299	Rejected
300-349	Rejected

4.5.9.1 Effect of particle size on thermal diffusivity

From the results, thermal diffusivity values were of order e^{-6} m^2s^{-1} and the values were different for different particle sizes of kaolin and ball clay. This was because small size particles of kaolin clay and ball clay resulted into an increase in a number of particles in a unit volume and this contributed to a reduction in the average interparticle distance of the clay matrix (Viruthagiri *et al.*, 2013). During pressing and firing of a clay sample made from small size particles, the voids in it tend to close reducing the porosity and this led to an increase in thermal diffusivity. Also, small particle sizes of kaolin clay and ball clay resulted into close contact points (Manukaji, 2003).

The implication was that only samples made by incorporating cow pie are good thermal insulators.

4.5.9.2 Effect of change of ratio on thermal diffusivity

There was no statistically significant difference between the values of thermal diffusivity of the samples for different particle sizes at level of significance $\alpha = 0.01$, however, at $\alpha = 0.05$, there was a statistically significant difference between the values of thermal diffusivity for the different clay-cow pie. The average calculated values of thermal diffusivity increased with the decrease in particle sizes of kaolin and ball clay, however, it was lower for the ratio 9:6:5 because of the increase in the amount of cowpie which burns out during firing creating many voids that act as heat insulators. Thermal diffusivity for the control experiment was very high because no pore former was used and so limited or no pores were formed after firing.

CHAPTER FIVE: CONCLUSION AND RECCOMENDATIONS

5:1 Introduction

The conclusion made on the results of this study was based on determination of thermal diffusivity and this required the measurement of the thermal conductivity, determination of the density and specific heat capacity of the samples for five different clay-cow pie particle sizes mixed in three different ratios.

5.2 Conclusion of the study

After determining the thermal conductivity of the samples for the clay-cow pie ratios 9:7:4 and 9:6:5 and 9:7:0, the null hypothesis, Ho_1 in section 1.5 was rejected because thermal conductivity at both levels of significance α=0.01 and α = 0.05 was affected by particle sizes of clay and cow pie.

The overall thermal conductivity values for particle sizes 0-74 µm, were 0.2264, 0.2256 and 0.2934 $Wm^{-1}K^{-1}$ for the clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively. Thermal conductivity values for particle size 75-89 µm were 0.2278, 0.2270 and 0.2903 $Wm^{-1}K^{-1}$ for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively. Thermal conductivity values for particle size 90-149 µm were 0.2262, 0.2249 and 0.2892 $Wm^{-1}K^{-1}$ for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively. Thermal conductivity values for particle size 150-299 µm were 0.2253, 0.2246 and 0.2896 $Wm^{-1}K^{-1}$ for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively and the thermal conductivity values for particle size 300-349µm for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively were 0.2251, 0.2228 and 0.2814 $Wm^{-1}K^{-1}$.

For density, the hypothesis, Ho_2 in section 1.5 was rejected because the density at both levels of significance α=0.01 and α = 0.05 for all clay-cow pie ratios was affected by particle sizes of clay and cow pie. The overall density values for particle sizes 0-74 µm were 1.2053, 1.1994 and 1.1837 gcm^{-3} for the clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively. The density for particle size 75-89 µm were1.2082, 1.2334, and 1.1717 gcm^{-3} for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively. The density for particle size 90-149 µm were 1.4556, 1.3815 and 1.1642 gcm^{-3} for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively, the density for particle size 150-299 µm density values were 1.1819, 1.2088 and

1.1678 gcm^{-3} for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively and the density for particle size 300-349 µm were 1.4683, 1.3062 and 1.1650 gcm^{-3} for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively.

For specific heat capacity, the hypothesis Ho_3 in section 1.5 was rejected because the specific heat capacity at both levels of significance α=0.01 and α = 0.05 for the clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 was affected by particle sizes of clay and cow pie. The overall specific heat capacity values for particle sizes 0-74 µm were 1.0172, 1.0131 and 1.1160 $Jg^{-10}C^{-1}$ for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively. Specific heat capacity values for particle size 75-89µm were1.0780, 1.0784 and 1.0363 $Jg^{-10}C^{-1}$ for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively. Specific heat capacity values for particle size 90-149 µm were 0.9986, 1.0861 and 1.0784 $Jg^{-10}C^{-1}$ for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively. Specific heat capacity values for particle size 150-299 µm were 1.0646, 1.0784 and 1.0574 $Jg^{-10}C^{-1}$ for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively and specific heat capacity values for particle size 300-349 µm were 1.0784, 1.0696 and 1.0797 $Jg^{-10}C^{-1}$ for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively.

After calculating the values of thermal diffusivity, the hypothesis Ho_4 in section 1.5 was rejected because the thermal diffusivity at both levels of significance α=0.01 and α = 0.05 for the clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 was affected by particle sizes of clay and cow pie. The overall thermal diffusivity values for particle sizes 0-74 µm were 0.1956, 0.2061 and 0.2777 m^2s^{-1} for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively. Thermal diffusivity values for particle size 75-89 µm were 0.2120, 0.2035 and 0.2653 m^2s^{-1} for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively. Thermal diffusivity values for particle size 90-149 µm were 0.1955, 0.2131 and 0.2567 m^2s^{-1} for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively. Thermal diffusivity values for particle size 150-299 µm were 0.2657, 0.2184 and 0.2554 m^2s^{-1} for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively and thermal diffusivity values for particle size 300-349 µm were 0.2077, 0.2137 and 0.2654 m^2s^{-1} for clay-cow pie ratios 9:7:4, 9:6:5 and 9:7:0 respectively.

In this study, a material having a low value of thermal diffusivity could be made from (90-149) µm particle sizes of kaolin and ball clay mixed with cow pie of (75-149 and 150-299) µm particle sizes and clay-cow pie ratio 9:7:4. This combination gave an average density of

1.1537 ± 0.1587gcm^{-3} and 1.1537 ± 0.0957 gcm^{-3} at levels of significance α=0.01 and α=0.05 respectively. Also, an average thermal conductivity of 0.2210 ± 0.0234 Wm^{-1}K^{-1} and 0.2210 ± 0.0141 Wm^{-1}K^{-1}at levels of significancy α=0.01 and α=0.05, respectively were obtained. This also is in the range of average thermal conductivity values of building materials with (0.023-2.9) ± 0.05 Wm^{-1}K^{-1} (Sunday *et al.*,2003), an average specific heat capacity of 0.9810 ± 0.365 Jg^{-10}C^{-1} and 0.9810 ± 0.365 Jg^{-10}C^{-1} at levels of significance α=0.01 and α=0.05 respectively and finally a calculated average value of thermal diffusivity of 1.883 ± 0.2286$(e)^{-7}$ m^{2}s^{-1} and 1.883 ± 0.1378$(e)^{-7}$ m^{2}s^{-1} at levels of significance α=0.01 and α=0.05 respectively. This is in a range of materials with low thermal diffusivity values (1.1-3.0)$(e)^{-7}$ m^{2}s^{-1} recommended for use as thermal insulators by the standards (ISO 13006). These results show that such a brick sample possess very interesting insulating properties compared to concrete and could contribute to energy saving once used as a building material. However, brick samples made from a combination of kaolin and ball clay only exhibited properties of high thermal diffusivity values and these did not match the required specifications for floor, wall and ceiling use.

The average calculated values of thermal diffusivity increased with the decrease in particle sizes of kaolin and ball clay. However, it was lower for the ratio 9:6:5 because of the increase in the amount of cow pie which burns out during firing creating many voids that act as heat insulators. Thermal diffusivity for the control experiment was very high because no pore former was used and so limited or no pores were formed after firing. This implies that pore formers should be incorporated in the clay while making bricks, this does not only produce light weight bricks but also improves on the insulation.

5.3 Recommendations

1) A study on the effect of thermal diffusivity developed from kaolin clay, ball clay and millet husks should be investigated. This is because in rural areas millet husks have not been put to use instead, they have always been burnt leading to air pollution. This could be achieved by using clay-millet husk particle size (90-149) µm particle sizes of kaolin and ball clay mixed with millet husk of (75-149 and 150-299) µm particle sizes and clay-millet husk ratio 9:7:4 to see whether lower values of thermal diffusivity could be obtained.

2) Further research should be conducted on the effect of varying compaction pressure on thermal diffusivity of a brick made from different particle sizes and ratio.

3) A study about the effect of different firing rates on mechanical properties of a brick made from clays mixed with of different particle sizes and different ratios also needs to be carried out.

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APPENDICES

APPENDIX A: RAW DATA

Raw data for Thermal conductivity determination for the ratio 9:7:4

Label	$k_1(Wm^{-1}K^{-1})$	$k_2(Wm^{-1}K^{-1})$	$k_3\ (Wm^{-1}K^{-1})$	$k_4(Wm^{-1}K^{-1})$	$k5\ (Wm^{-1}K^{-1})$
A1	0.226	0.218	0.217	0.216	0.215
A2	0.225	0.221	0.221	0.220	0.220
A3	0.225	0.228	0.226	0.225	0.225
A4	0.227	0.224	0.224	0.223	0.223
A5	0.225	0.220	0.218	0.217	0.215

Raw data for Thermal conductivity determination for the ratio 9:6:5

Label	$k_1(Wm^{-1}K^{-1})$	$k_2(Wm^{-1}K^{-1})$	$k_3\ (Wm^{-1}K^{-1})$	$k_4(\ Wm^{-1}K^{-1})$	$k_5\ (Wm^{-1}K^{-1})$
D1	0.226	0.216	0.215	0.214	0.213
D2	0.225	0.220	0.220	0.220	0.215
D3	0.223	0.228	0.227	0.223	0.221
D4	0.222	0.225	0.215	0.223	0.218
D5	0.223	0.222	0.217	0.220	0.222

Raw data for Thermal conductivity determination for the ratio 9:7:0

Label	$k_1(Wm^{-1}K^{-1})$	$k_2\ (Wm^{-1}K^{-1})$	$k_3\ (Wm^{-1}K^{-1})$	$k_4(Wm^{-1}K^{-1})$	$k_5\ (Wm^{-1}K^{-1})$
E1	0.226	0.218	0.217	0.216	0.215
E2	0.225	0.221	0.221	0.220	0.220
E3	0.225	0.228	0.226	0.225	0.225
E4	0.227	0.224	0.224	0.223	0.223
E5	0.225	0.220	0.218	0.217	0.215

Raw data for mass determination for the ratio 9:7:4

Label	m_1/kg	m_2/kg	m_3/kg	m_4/kg	m_5/kg
A1	0.1099	0.1103	0.1099	0.1121	0.1084
A2	0.1002	0.1099	0.1071	0.1109	0.1097
A3	0.1092	0.1056	0.1063	0.1061	0.1077
A4	0.1014	0.2083	0.1073	0.1063	0.1064
A5	0.1045	0.1051	0.1075	0.1013	0.1052

Raw data for mass determination for the ratio 9:6:5

Label	m_1/kg	m_2/kg	m_3/kg	m_4/kg	m_5/kg
D1	0.1085	0.1098	0.1091	0.1067	0.1071
D2	0.1062	0.1077	0.1090	0.1079	0.1079
D3	0.1048	0.1041	0.1071	0.1091	0.1043
D4	0.1074	0.1049	0.1099	0.1027	0.1020
D5	0.1019	0.1053	0.1071	0.1062	0.1000

Raw data for mass determination for the ratio 9:7:0

Label	m_1/kg	m_2/kg	m_3/kg	m_4/kg	m_5/kg
E1	0.1079	0.1089	0.1089	0.1079	0.1087
E2	0.1091	0.1080	0.1063	0.1079	0.1051
E3	0.1062	0.1026	0.1049	0.1098	0.1072
E4	0.1054	0.1049	0.1031	0.1076	0.1063
E5	0.1041	0.1079	0.1021	0.1050	0.1008

Raw data for volume determination for the ratio 9:7:4

Label	V_1 /cm^3	V_2/cm^3	V_3 /cm^3	V_4 /cm^3	V_5/ cm^3
A1	93.10	93.67	92.97	93.48	93.22
A2	93.00	93.35	92.78	93.49	93.59
A3	92.90	92.00	94.20	91.99	92.58
A4	92.40	92.90	95.12	90.52	92.45
A5	92.31	92.12	92.24	92.90	90.20

Raw data for volume determination for the ratio 9:6:5

Label	V_1 /cm^3	V_2/cm^3	V_3 /cm^3	V_4 /cm^3	V_5/ cm^3
D1	92.99	92.87	92.55	91.83	92.92
D2	92.80	92.74	93.67	92.87	93.22
D3	92.20	92.89	92.83	93.71	93.59
D4	92.10	91.91	91.10	92.59	92.58
D5	92.00	92.99	93.41	91.48	92.45

Raw data for volume determination for the ratio 9:7:0

Label	V_1 /cm^3	V_2/cm^3	V_3 /cm^3	V_4 /cm^3	V_5/ cm^3
E1	91.99	91.31	91.17	91.59	90.98
E2	90.92	90.00	91.01	90.67	98.05
E3	89.00	89.28	89.14	88.95	87.97
E4	88.99	88.12	88.88	88.93	87.42
E5	87.54	86.39	90.93	87.50	87.88

Raw data for density determination for the ratio 9:7:4

Label	ρ_1 (gcm^{-3})	ρ_2 (gcm^{-3})	ρ_3 (gcm^{-3})	ρ_4 (gcm^{-3})	ρ_5 (gcm^{-3})
A1	1.180	1.077	1.175	1.097	1.132
A2	1.178	1.177	1.148	1.166	1.141
A3	1.182	1.154	1.128	1.128	1.165
A4	1.212	1.186	1.153	1.174	1.166
A5	1.163	1.172	1.163	1.151	1.141

Raw data for density determination for the ratio 9:6:5

Label	ρ_1(gcm^{-3})	ρ_2 (gcm^{-3})	ρ_3 (gcm^{-3})	ρ_4 (gcm^{-3})	ρ_5 (gcm^{-3})
D1	1.167	1.145	1.137	1.166	1.108
D2	1.182	1.150	1.121	1.141	1.132
D3	1.179	1.174	1.154	1.206	1.147
D4	1.162	1.157	1.164	1.109	1.161
D5	1.153	1.163	1.114	1.102	1.082

Raw data for density determination for the ratio 9:7:0

Label	ρ_1 (gcm^{-3})	ρ_2 (gcm^{-3})	ρ_3 (gcm^{-3})	ρ_4 (gcm^{-3})	ρ_5 (gcm^{-3})
E1	1.173	1.200	1.193	1.184	1.189
E2	1.193	1.200	1.149	1.190	1.342
E3	1.194	1.168	1.177	1.160	1.123
E4	1.178	1.191	1.234	1.210	1.200
E5	1.195	1.072	1.219	1.150	1.147

The average values of mass and temperature for determining the specific heat capacity of clay samples

	mc=70.1 g	Ɵ3=190⁰ C	Ɵ1=27	cc=0.385	cw=4.182
SAMPLE	ms/kg	ms/g	mw/g	Ɵ2/0C	C($Jg^{-1}\,{}^{0}C^{-1}$)
A5,1	0.0362	36.20	190.0	34.4	1.0793
A5,2	0.0365	36.47	190.0	34.41	1.0729
A5,3	0.0369	36.98	190.0	34.47	1.0670
A5,4	0.0370	37.01	190.0	34.43	1.0602
A5,5	0.0369	36.92	190.0	34.39	1.0568
A4,1	0.0367	36.7	189.1	34.32	1.0478
A4,2	0.0367	36.66	189.1	34.30	1.0459
A4,3	0.0364	36.41	189.1	34.37	1.0637
A4,4	0.0359	35.94	189.1	34.11	1.0378
A4,5	0.0361	36.12	189.1	34.30	1.0615
A3,1	0.0360	36.00	187.9	33.89	0.9965
A3,2	0.0361	36.14	187.9	33.80	0.9791
A3,3	0.0362	36.23	187.9	33.88	0.9886
A3,4	0.0364	36.4	187.9	33.71	0.9587
A3,5	0.0361	36.12	187.9	33.81	0.9811
A2,1	0.0368	36.8	187.8	34.20	1.0202
A2,2	0.0368	36.83	187.8	34.33	1.0386
A2,3	0.0359	35.99	187.8	34.47	1.0841
A2,4	0.0368	36.81	187.8	34.40	1.0496
A2,5	0.0368	36.82	187.8	34.41	1.0508
A1,1	0.0370	37.00	188.8	34.10	1.0051
A1,2	0.0371	37.09	188.8	34.12	1.0056
A1,3	0.0369	36.98	188.8	34.10	1.0056
A1,4	0.0370	37.01	188.8	34.16	1.0137
A1,5	0.0369	36.92	188.8	34.17	1.0176
D5,1	0.0363	36.3	188.7	34.30	1.0541
D5,2	0.0361	36.11	188.7	34.29	1.0581
D5,3	0.0367	36.7	188.7	34.15	1.0202
D5,4	0.0359	35.99	188.7	34.23	1.0525
D5,5	0.0364	36.41	188.7	34.37	1.0615
D4,1	0.0365	36.5	188.2	34.59	1.0892
D4,2	0.0360	36.00	188.2	34.50	1.0906
D4,3	0.0364	36.41	188.2	34.47	1.0738
D4,4	0.0366	36.61	188.2	34.56	1.0814
D4,5	0.0366	36.57	188.2	34.49	1.0721
D3,1	0.0360	36.00	189.7	34.37	1.0791
D3,2	0.0359	35.9	189.7	34.32	1.0744
D3.3	0.0361	36.07	189.7	34.12	1.0388
D3,4	0.0361	36.12	189.7	34.19	1.0480

D3,5	0.0362	36.23	189.7	34.40	1.0768
D2,1	0.0362	36.2	189.9	34.21	1.0498
D2,2	0.0360	36.00	189.9	34.11	1.0403
D2,3	0.0362	36.17	189.9	34.10	1.0339
D2,4	0.0363	36.27	189.9	34.23	1.0508
D2,5	0.0363	36.33	189.9	34.24	1.0506
D1,1	0.0371	37.1	189.0	34.16	1.0122
D1,2	0.0370	36.99	189.0	34.10	1.0064
D1,3	0.0369	36.9	189.0	34.00	0.9940
D1,4	0.0371	37.12	189.0	34.02	0.9910
D1,5	0.0374	37.4	189.0	34.17	1.0056
E5,1	0.0369	36.9	188.00	34.49	1.0614
E5,2	0.0369	36.88	188.00	34.40	1.0487
E5,3	0.0363	36.29	188.00	34.43	1.0702
E5,4	0.0364	36.41	188.00	34.52	1.0802
E5,5	0.0362	36.2	188.00	34.50	1.0835
E4,1	0.0361	36.1	188.6	34.30	1.0594
E4,2	0.036	36.00	188.6	34.11	1.0334
E4,3	0.0361	36.09	188.6	34.23	1.0491
E4,4	0.0361	36.11	188.6	34.37	1.0698
E4,5	0.0362	36.17	188.6	34.15	1.0346
E3,1	0.0371	37.10	189.2	34.40	1.0489
E3,2	0.0373	37.29	189.2	34.49	1.0568
E3,3	0.0371	37.12	189.2	34.29	1.0320
E3,4	0.0372	37.16	189.2	34.37	1.0427
E3,5	0.0371	37.11	189.2	34.39	1.0471
E2,1	0.0370	37.00	189.0	34.30	1.0358
E2,2	0.0372	37.22	189.0	34.23	1.0193
E2,3	0.0371	37.14	189.0	34.11	1.0038
E2,4	0.0372	37.16	189.0	34.17	1.0121
E2,5	0.0373	37.29	189.0	34.32	1.0307
E1,1	0.0369	36.90	188.9	34.20	1.0232
E1,2	0.0367	36.70	188.9	34.20	1.0287
E1,3	0.0368	36.76	188.9	34.29	1.0405
E1,4	0.0368	36.81	188.9	34.99	1.1440
E1,5	0.0366	36.57	188.9	34.12	1.0204

Raw data for specific heat determination for the ratio 9:7:4

Label	c_1/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_2/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_3/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_4/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_4/x10^3 ($Jg^{-1}\,^0C^{-1}$)
A1	1.005	1.020	0.996	1.048	1.079
A2	1.006	1.039	0.979	1.046	1.073
A3	1.006	1.084	0.989	1.064	1.067
A4	1.014	1.050	0.959	1.038	1.060
A5	1.018	1.051	0.981	1.062	1.057

Raw data for specific heat determination for the ratio 9:6:5

Label	c_1/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_2/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_3/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_4/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_5/x10^3 ($Jg^{-1}\,^0C^{-1}$)
D1	1.012	1.050	1.079	1.089	1.054
D2	1.006	1.040	1.074	1.091	1.058
D3	0.994	1.034	1.039	1.074	1.020
D4	0.991	1.051	1.048	1.081	1.053
D5	1.006	1.051	1.077	1.072	1.061

Raw data for specific heat determination for the ratio 9:7:0

Label	c_1/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_2/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_3/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_4/x10^3 ($Jg^{-1}\,^0C^{-1}$)	c_5/x10^3 ($Jg^{-1}\,^0C^{-1}$)
E1	1.023	1.036	1.049	1.059	1.061
E2	1.029	1.019	1.057	1.033	1.049
E3	1.040	1.004	1.032	1.049	1.070
E4	1.144	1.012	1.043	1.070	1.080
E5	1.020	1.031	1.047	1.035	1.083

Raw data for thermal diffusivity determination for the ratio 9:7:4

Label	D_1/x10^{-6}(m^2/s)	D_2x10^{-6}(m^2/s)	D_3/x10^{-6} (m^2/s)	D_4/x10^{-6}(m^2/s)	D_5/x10^{-6}(m^2/s)
A1	0.193	0.206	0.184	0.206	0.205
A2	0.192	0.195	0.189	0.198	0.207
A3	0.191	0.214	0.198	0.212	0.206
A4	0.189	0.198	0.187	0.197	0.203
A5	0.196	0.197	0.184	0.200	0.199

Raw data for thermal diffusivity determination for the ratio 9:6:5

Label	D_1/x10^{-6}(m^2/s)	D_2x10^{-6}(m^2/s)	D_3/x10^{-6}(m^2/s)	D_4/x10^{-6}(m^2/s)	D_5/x10^{-6}(m^2/s)
D1	0.196	0.198	0.204	0.200	0.203
D2	0.191	0.199	0.211	0.210	0.200
D3	0.188	0.201	0.204	0.199	0.197
D4	0.189	0.204	0.194	0.217	0.198
D5	0.195	0.201	0.210	0.214	0.218

Raw data for thermal diffusivity determination for the ratio 9:7:0

Label	D_1/x10^{-6}(m^2/s)	D_2x10^{-6}(m^2/s)	D_3/x10^{-6}(m^2/s)	D_4/x10^{-6}(m^2/s)	D_5/x10^{-6}(m^2/s)
E1	0.249	0.245	0.231	0.235	0.207
E2	0.246	0.223	0.261	0.247	0.179
E3	0.249	0.236	0.240	0.248	0.233
E4	0.287	0.245	0.244	0.255	0.259
E5	0.242	0.270	0.237	0.249	0.249

APPENDIX B: ANOVA CALCULATIONS

F-VALUE

Total variance=Total variance between the group + total variance within the group

$SST=SS_B + SS_W$

$SST = \sum x^2 - \frac{1}{kn}(\sum x)^2$

Where $SSw = \frac{(\sum x)2}{k} - \frac{1}{kn}(\sum x)^2$, SS_B = a – b’ $MS_B = \frac{SSB}{k-1}$ and $MS_W = \frac{SSw}{k(n-1)}$

SUMMARY OF ANOVA

Source of variance	Sum of squares	Degree of freedom	Mean variance	F-value
Between samples	SSE	k (n-1)	$\frac{SSE}{k-1} = MSE$	$\frac{MSTr}{MSE}$
Within samples	SSTr	k-1	$\frac{SSTr}{k(n-1)} = MSTr$	
Total variance	SST	kn-1		

Where SSTr= Total variance within the samples

SSE= Total variance between samples

SST= Total variance of data

k= number of independent variables

Mean error at α=0.010 is Stdev/5^0.5*4.604

Mean error at α=0.050 is Stdev/5^0.5*2.776