

**A STUDY OF THE COEFFICIENT OF THERMAL DIFFUSIVITY OF BUILDING
BRICKS MADE FROM CLAY AND LOCAL DISTILLERY WASTE MIXTURE**

BY

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Declaration

I, Aguma Patrick do hereby declare that this Dissertation contains my original research work and has not been submitted to any academic institution for an academic award.

Signature:

Date:

APPROVAL

This study by Aguma Patrick was carried out under our close supervision and guidance. The dissertation is hereby cleared to be presented to the Board of Examiners and Senate of Kyambogo University.

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DEDICATION

This dissertation is dedicated to my Parents, Mrs. Chwa Norah and Mr. Chwa David.

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ABSTRACT

The use of various wastes in clay for brick making has significantly gained research attention. This is because most of these wastes especially organic ones burn during firing leaving pores (voids) in the bricks thus lowering heat flow across such bricks. In this case, bricks can act as insulators in walls thus cutting energy costs in buildings. In this study, the coefficient of thermal diffusivity of bricks made from clay and local distillery waste mixture was investigated. Local distillery waste is the end waste obtained when the crude brew is made from cassava flour mixed with water, fermented, roasted, dried, fermented again, and distilled. The proportion of clay replaced by the local distillery waste in the mixture was 0, 4, 8, 12, 16, and 20 wt.%. The bricks were then fired from 600-1100 °C in steps of 100 for one hour in an electric furnace. The coefficient of thermal diffusivity was calculated from the experimental values of; thermal conductivity which was measured using quick thermal conductivity meter (QTM-500) with sensor probe PD-11, specific heat capacity which was measured by method of mixture and density obtained from measured values of mass and volume of the samples. The study results presented a general decrease in the values of the coefficient of thermal diffusivity as the content of local distillery wastes added to clay increased across all temperatures. The coefficient of thermal diffusivity was observed to steadily decrease from firing temperatures 600 °C through to lowest values at 900 °C. However, there was an increase in the coefficient of thermal diffusivity in a range of 1000 to 1100 °C. An optimal value of $2.36 \times 10^{-7} \text{ m}^2\text{s}^{-1}$ at 900 °C was exhibited by samples with 16 wt.% local distillery waste. This value is below the accepted standard of $5.61 \times 10^{-7} \text{ m}^2\text{s}^{-1}$. Therefore, local distillery waste is suitable for use in bricks as thermal insulating material.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Soil materials such as clay and sand are readily found, thus making them cheap and the most viable materials for making construction materials, for example, bricks and tiles. Advanced production through the use of fabrication machines has made it easier to produce better-quality clay products in bulk. This continues to render soil materials even more as a source of building materials for financial and resource-challenged countries (Olotuah, 2002).

Clay remains the most highly used material in the manufacture of many traditional ceramics like earthenware, stoneware, bricks, and cement. Best ceramics products result in clay having; a low swelling phase, low weight loss, and low shrinkage after drying and firing (Aras, 2004).

Clay can be formed into building blocks, fired bricks, and unfired bricks called adobe building bricks. However, clay is most suitable for bricks making specifically because of; its plasticity making shaping or molding easy, its ability to remain strong in its shape when molded and during air drying, and its ability to fuse when fired at 950 °C (Andy Sutton *et al.*, 2011).

Clay brick remains the oldest and most long-lasting construction material in the world. Clay brick's history dates back to as far as 10000 BC, up to date clay renders durability and a beautiful appearance to constructions of buildings (Quagliarini *et al.*, 2010; Sahu & Singh, 2017). The use of organic materials in architectural design especially clay brick is continuously gaining ground. Following the current trend of apartments, rentals, residential homes, and business units, it has become a desirable building material of choice because of its great insulating qualities. A house that remains conducive in both hot and cold kinds of weather is desired in the building technology currently and clay bricks, in this case, are well known for their high thermal insulation quality which renders this desire (Quagliarini *et al.*, 2010; Sahu & Singh, 2017).

Clay building bricks are highly durable, require minimal or no maintenance and they offer favorable conditions of life through improved indoor comfort due to their porous nature, and are highly resistant to fire and moisture. Energy consumption in buildings remains significantly costly in extreme climates. However, clay bricks offer high thermal insulation with equally high heat retention properties. Related work by Bwayo,(2014) presented a

decrease in thermal diffusivity as the particle size of sawdust added to clay increased, Phonphuak *et al.*, (2020) also investigated the addition of sawdust into clay and saw a decrease in the values of thermal conductivity from 0.47 to 0.22 $\text{Wm}^{-1}\text{K}^{-1}$, Muñoz *et al.*, (2020), incorporated paper pulp residues (PPR) into the kaolinite red clay, Their study observed the lowering brick's thermal conductivity from 0.53 $\text{Wm}^{-1}\text{K}^{-1}$ to 0.41 $\text{Wm}^{-1}\text{K}^{-1}$ for samples from 0 % to 17.5 %. Ahmad *et al.*, (2017), also investigated how the coal and wheat husk addition into clay impacted the thermal properties of fired clay bricks. The authors reported that the coefficient of thermal diffusivity was observed to decrease by 15-60 % for 5 wt. %-50 wt. % of coal added and also decreased by 49-92 % for 5-50 wt. % of wheat husks added. Srisuwan, (2018), investigated the addition of grass (GA), coconut husk (CH), and sugar bagasse (SB) into the clay for the potential production of the fired bricks of improved thermal insulation. They observed that thermal conductivity varied from 0.45 $\text{Wm}^{-1}\text{K}^{-1}$ to 0.21 $\text{Wm}^{-1}\text{K}^{-1}$ based on the GA, CH, and SB contents from 2.5 wt. % to 7.5 wt. %. The results showed that agricultural wastes are potentially sustainable building materials that can improve thermal insulation. All the above studies were done based on the possibility of improving the insulating properties of building bricks. The addition of these additives leads to the creation of pores in bricks thus improving on thermal insulation of bricks. Thus, there are growing concerns on how the production and installation costs in buildings can be minimized, while also attaining better insulation properties. There is therefore, a need to come out with discoveries on the best insulation materials that would render solutions to high-energy costs in buildings, since the current solutions such as sandwich panels, polystyrene, and heat insulating mortars, all increase building costs (Arsenovic *et al.*, 2010).

The thermal comfort of a building is influenced by factors such as convection, conduction, and radiation. However, conduction is the major source of heat transfer across building walls. Thermal diffusion through a medium is low at lower thermal diffusivity and high at higher thermal diffusivity. The architectural value of thermal diffusivity is related to the flow of heat through the materials at some rate. The non-equilibrium flow of heat through a medium is paramount in the management of the interior comfort of buildings. This is through the principle of thermal insulation where the brick wall becomes one that keeps indoor comfort in both hot and cold weather. Subsequently, this reduces the cost of energy consumption which would come from the use of artificial means (Bwayo & Obwoya, 2014).

The tropical cities (Kampala and Kinshasa), arid regions (Sudan and Egypt), and highly humid regions (Russia, Finland, and Norway), need an appropriate concept of the heat

balance of the thermal environment. Thus, there is a high need for highly insulating bricks for walling purposes. A vast amount of waste, including fibers, pulps, and grains' wastes, is typically realized as a result of production processes like farming and manufacturing items. These are disposed of in the landfill and in some cases openly burnt. However, the improper management of some of these wastes poses significant risks to the environment. Efforts have been made to control this vice by incorporating these wastes in the building industry and particularly brick making. Bricks made from clay mixed with natural fibers and grains' wastes give a porous structure. This improves the heat and sound-insulating properties of the products (Chan, 2011).

Currently, many of the buildings are constructed using fired bricks made from clay or clay mixed with other additives. In the latter case, early research and recipes showed that wood-based additives like sawdust and wood chips were used providing conducive thermal comfort but most recently, polymers and agricultural waste materials or by-products such as rice-peel or seed-shell, granite sawing wastes, harbor sediments, sugarcane bagasse ash, introduced as additives in bricks manufacturing in a bid to improve thermal properties of bricks (Bwayo & Obwoya, 2014; Demir, 2008; Aeslina Abdul Kadir & Sarani, 2012; Muñoz Velasco *et al.*, 2014; Sahu & Singh, 2017).

However, research is ongoing to find the best bricks for thermal insulation. Thus, there is a need to explore more of the expected pore-forming organic materials for clay brick-making to improve thermal insulation in buildings. Local distillery waste as end waste from distillation of crude brew obtained from cassava flour is added to clay for brick making. Local distillery waste being a product of an organic material burns leaving pores in bricks thus lowering thermal conduction through the brick. This will eventually lower the energy and maintenance costs of buildings. Local distillery waste has never been explored for use as a pore-forming additive in clay bricks.

The study of how the coefficient of thermal diffusivity of bricks made from clay mixed with different materials changes under different firing temperatures is important in determining the right bricks for construction. The minimum accepted value of the coefficient of thermal diffusivity is $5.61 \times 10^{-7} m^2s^{-1}$ (ASTM C1363,2019). This study thus, focused on the determination of the coefficient of thermal diffusivity of bricks made from the mixture of clay and local distillery waste.

1.2 Statement of the Problem

Indoor thermal comfort is a necessity in buildings but it's a challenge at extreme temperatures that is in very cold and hot temperatures. In these cases, buildings have been designed to maintain thermal comfort through the use of air conditioning, electric and coal heating, and use of many other methods, resulting in significant building maintenance costs through high energy costs in buildings. Studies are continuously ongoing to improve thermal comfort in a bid to cut down energy costs in buildings. This has been through the addition of pores forming organic materials such as wood chips, sawdust, rice and wheat husk, tea waste, sunflower seed cake, etc., in clay for brick making. Buildings with good indoor thermal comfort are required to have low values of coefficient of thermal diffusivity. Research is being conducted on brick materials that possess this attribute. This study evaluates the coefficient of thermal diffusivity of locally produced bricks made of clay and local distillery waste which has never been used in brick production.

1.3 Purpose of the Study

To analyze the coefficient of thermal diffusivity of building brick made from a mixture of clay and local distillery waste, fired at different firing temperatures.

1.4 The Objectives of the Study

The specific objectives of the study are to;

1. Characterize the chemical composition of 'Ayole' swamp clay and local distillery waste.
2. Determine the coefficient of thermal diffusivity of the prepared samples.
3. Compare the coefficient of thermal diffusivity of samples made from a mixture of clay and local distillery waste, with the sample made from only clay.

1.5 Significance of the Study

This study will unearth more scientific knowledge which may help researchers to further their discoveries in material and building science.

This study may provide an appropriate building material with a low energy maintenance cost, to civil and building engineers. Thus, addressing the sustainable development goal (03) of good health and well-being.

This study may also help environmentalists realize the need to come up with policies to regulate open-fill disposal of dangerous wastes like local distillery wastes in the environment thereby saving the ecosystem. Thus, addressing the sustainable development goal (06) of clean water and sanitation.

1.6 Scope of the Study

In this study, clay and local distillery waste in powdered form were used to make the samples. Clay was obtained from the Ayole swamp in Aduku sub-county, Kwania district which is 33 kilometers Northwest of Lira city in Uganda. Figure 1.1 shows the location of the clay deposits and local distillery waste.

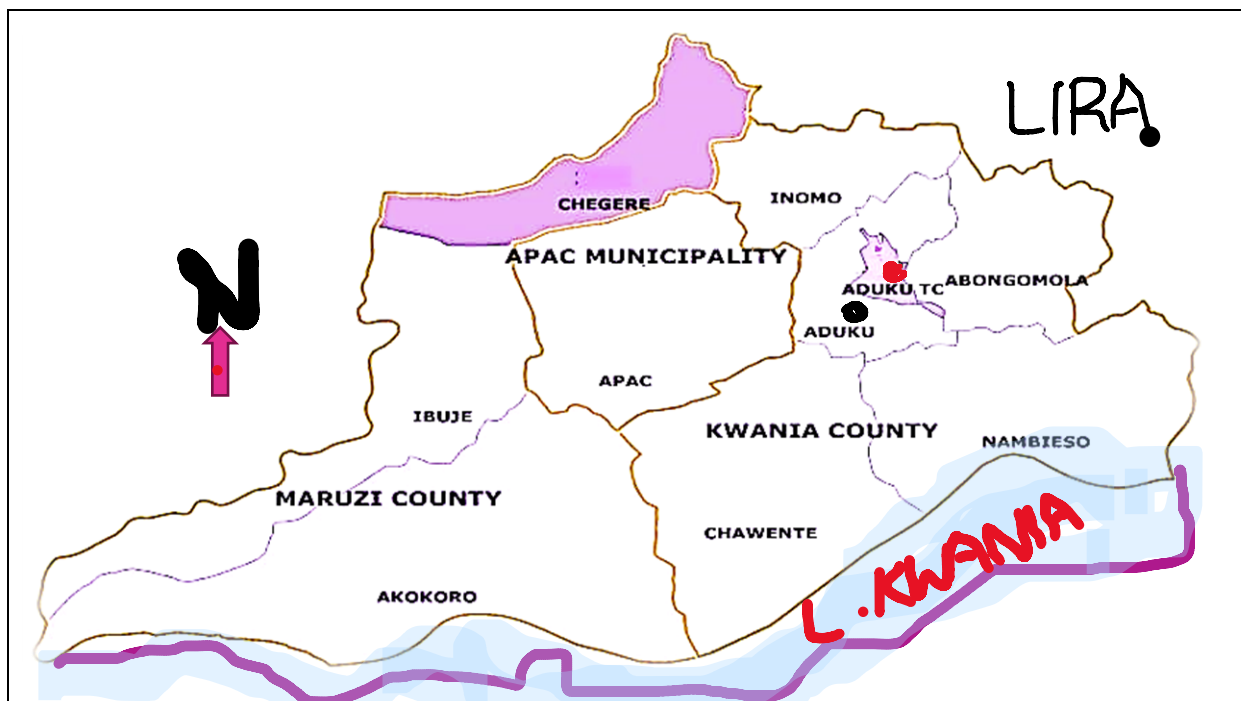


Figure 1.1: Map of Apac showing Aduku Town Council and Aduku sub-county

The local distillery waste was obtained from a local brew distiller in Ikwera ward, Aduku town council which is 36 kilometers Northwest of Lira city in Uganda. The local distillery waste used in this study is the end product of the distillation of crude waragi made from cassava flour as the main ingredient.

A total of 144 fired samples of the dimension 7.8 cm by 4.0 cm by 3.0 cm, (four replicates of samples of six different proportions fired at six different temperatures) were used in this study. The mean/average values of the measured quantities for these replicates were obtained and from it, coefficients of thermal diffusivity were calculated. This study took six months.

CHAPTER TWO: REVIEW OF THE RELATED LITERATURE

2.1 Introduction

The following were reviewed in this chapter; Mineralogy and chemical composition of the clay soil, thermal properties dependence on different additives (wastes) used in clay bricks production, and effect of temperature on thermal properties of clay.

2.2 Mineralogy and chemical composition of the clay soil

Clay minerals fall under a wider class of sheet silicates called phyllosilicates. The clay properties such as thermal properties are generally influenced by clay mineralogical structure. The clay minerals types include;

Kaolinite; kaolinite's chemical composition is given by the formula $Al_2O_3 \cdot 2SiO_2 \cdot 2(H_2O)$ Kaolinite is a result of feldspar's weathering. It is physically a white powdery material that poorly expands and absorbs water. Thus, kaolinite remains the most suitable type of clay for construction (Cuevas *et al.*, 2009).

Mica, in the clay fraction presents itself with very poor crystallinity, lower potassium ion content, and higher water content, and in some cases, mica replaces Fe^{2+} and Fe^{3+} in its octahedral sheets and Ca^{2+} in the interlayer. Manganese, vanadium, lithium, chromium, titanium, and several other cations are found in different quantities in clay-sized micas (Waltham, 2009).

Illite clay is a result of feldspars and felsic silicates undergoing weathering (Cuevas *et al.*, 2009). Thus, the illite clays are the ones that do not expand but are often present as mixed-layer clays with montmorillonite and/or chlorite (Afaf zarkik, 2015).

The major categories of clay minerals are kaolinite, illite, and montmorillonite. The kaolinite layers are fairly weakly bonded whereas the illite has strong bonding of its possession of potassium ion, and strong in montmorillonite as a result of its possession of calcium and sodium. Thus, when used in brick production could produce brick with better physical, thermal and mechanical properties. This would reduce economic losses in dealing with broken bricks and energy-inefficient structures.

It is important to know clay mineral properties and how they are characterized before one ventures into clay brick production and its sustainable use in construction.

For example, clay minerals identification and quantification. The effect of these clay minerals on Brick's properties depends on the way carbonates, oxides, and hydroxides, sulfates are formed. The swelling and double-layer formation, and influences phase changes during firing. However, Clay shows some kind of similarity in principal chemical components such as silica (SiO_2), Alumina (Al_2O_3), iron oxide (Fe_2O_3), and calcium oxide (CaO). However, different clay deposits tend to show variations in the concentration of these chemical components (Ombaka, 2016).

Silica (SiO_2) is the most abundant chemical component in clay and it can also be termed as free-quartz grain. Clay mostly contains silica in the range of 45 wt.% to 60 wt.%. The more silica the less water is required for molding and this also accounts for the non-plastic character. An increase in silica quantity leads to reduced dry and firing shrinkage. Thus, the fired specimen tends to show high porosity due to shrinkage during the cooling stage after the firing process. This enables the specimen to control the flow of heat from one surface to another thus helping to improve the thermal performance of materials. The resulting specimen will have lower density and will be mechanically resistant than clay with less silica content. However, above 60 % silica, clays become more suitable for making refractory bricks (Ombaka, 2016). The higher percentage of silica (SiO_2) in clay indicates its good thermal properties. Silica is used in the ceramics industry mainly for thermal insulation, refractories, abrasives, and fiber-reinforced composites (Milosevic, 2019).

Alumina (Al_2O_3) is the second most extended clay oxide. During the firing process, alumina reacts with oxygen and forms mullite. The crystalline structural arrangement of mullite makes it have an increase in chemical and mechanical resistance in the clay material. Suitable Alumina ranges from 10 to 20 % in fired clay bricks which are produced for masonry walls. Whereas for refractory bricks, its percentage can be up to 40 % (Heniegal *et al.*, 2020; Rafukka *et al.*, 2013).

Iron oxide (Fe_2O_3), content does not go beyond 10 %, and higher iron oxide percent contributes to discoloration which is a result of the presence of pyrite (SFe) or marcasite (S_2Fe) during firing. (Heniegal *et al.*, 2020; Rafukka *et al.*, 2013).

Calcium oxide (CaO); clay with a calcium oxide content of less than 9 wt.% is treated as non-calcareous whereas beyond 9 wt.% clay is known as calcareous. This clay compound presents bricks of low porosity and high density. This is because calcium oxide is partly a fluxing oxide which helps to bind particles thus lowering porosity (Rufukka *et al.*, 2013).

Sodium, calcium, manganese, potassium, and magnesium compounds normally found in the clays are fluxing agents that melt during firing thus producing a glassy phase that acts to bind the brick particles (Elert *et al.*, 2004).

2.3 Effect of different additives used in clay bricks on their thermal properties

2.3.1 Thermal properties of bricks

Thermal conductivity is a material's ability to conduct heat, which is generally defined as the rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference ($\text{Wm}^{-1}\text{K}^{-1}$). Low thermal conductivity values clearly show that a material poorly conducts heat. Low thermal conductivity is the most suitable this is because heat conduction through a medium is low, especially in extreme temperatures. This helps to maintain heat indoors in cold climates and also controls heat transfer indoors in hot climates. The thermal conductivity of the clay bricks depends on the following factors; pore size, pore volume fraction, and mineralogical composition of raw materials. This is because the more porous the bricks are, the better they can control heat flow thus good thermal performances of the brick product. Thermal conductivity depends on the structure of materials. Highly dense materials transfer heat easily and fast whereas low-density materials present low thermal conductivity mainly because of the addition of other lightweight materials (Goodhew & Griffiths, 2005).

Kormann. (2007), investigated the thermal conductivity of the bricks at firing temperatures from 700 °C – 1400 °C and it reported lower values of thermal conductivity of less than 0.3 $\text{Wm}^{-1}\text{K}^{-1}$ for samples fired below 1050 °C.

According to Arsenovic *et al.*(2010), the thermal properties of clay depend on; the raw materials used in brick production, volume mass, and the total voids fraction of clay. This can also be enhanced by mixing the clay with combustibles or lightweight materials. These in most cases are organic wastes and the more plastic the clay is, the lower the volume mass and the more the void configurations. The void configuration here includes the number of voids, void arrangement, and void fraction. The greater the void configuration, the slower the rate of heat flow through a substance (medium). Also, the thermal properties of a brick can be affected by the different firing temperatures depending on the content of the bricks. Like for most bricks with additives, the suitable firing temperature was observed to be in the range of 900-1100 °C. However, many organic matter-clay bricks have an optimum temperature falling in the range of 900-950 °C for good thermal properties of the bricks (Bwayo & Obwoya, 2014; Phonphuak *et al.*, 2020).

The specific heat capacity of a material is the amount of heat required to raise the temperature of the one-kilogram mass of a substance or material by one Kelvin. Specific heat capacity remains a key parameter in the determination of the thermal insulation of a material (Ayugi *et al.*, 2011). Materials with higher specific heat capacity values absorb more energy before causing a change in their body temperature.

Thermal diffusivity is a measure of the rate (speed) at which heat travels from one point to another by diffusion. It also indicates how fast a material's temperature can change with the surrounding temperature. Mathematically, thermal diffusivity varies inversely with the specific heat capacity and directly with thermal conductivity (Salmon *et al.*, 2007). Materials with higher thermal diffusivity adjust rapidly to ambient temperature because heat is easily conducted through it.

The coefficient of thermal diffusivity is a thermo-physical parameter that is independent of every material. This Coefficient of thermal diffusivity is simply a measure of the heat flux rate through a material and it physically describes the speed at which heat flows through a material. It depends on the structural arrangement and composition of materials. For instance, the particle size of the raw materials impacted the thermal diffusivity so much that, larger particle sizes resulted in large pores created in the fired clay product thus, leaving large air spaces in the clay material. This interferes with the heat conduction through the material, thus lowering the value of thermal diffusivity. The eventual clay product is so light weighted. Materials of smaller particle sizes when compacted together leave very small air spaces, resulting in higher thermal conduction across the material and thus the high value of the coefficient of thermal diffusivity (Bwayo & Obwoya, 2014).

The practical importance of thermal diffusivity is related to the diffusion of heat into the medium or material at a given temperature rate. The high thermal mass of clay bricks allows restricted heat flow during temperature changes (Binici *et al.*, 2005).

2.3.2 Additives (wastes) used in clay bricks and how they influenced the bricks' thermal properties

Humans and their activities such as agriculture and industrialization produce a lot of waste and by-products example; alcohol brew end waste, tea waste, shea butter seed cake, rice, wheat, coffee husks, maize cobs, and sunflower seed cake. It is to this effect that materials and engineering scientific researchers worldwide have turned attention to the incorporation of most of these wastes as additives in brick production. This in many cases has produced good thermally insulated bricks thus reducing the energy cost for houses built with such bricks.

The study by Bal *et al.* (2012), underlined that the millet waste addition to laterite-based bricks strongly decreased the thermal conductivity of bricks. Bwayo & Obwoya. (2014), investigated the dependence of the coefficient of thermal diffusivity of building bricks made from sawdust, ball clay, and kaolin clay on particle size and all samples were fired at 950 °C. Thermal diffusivity was then calculated from the expression involving measured values of specific heat capacity, thermal conductivity, and density of the brick samples. The study thus concluded that the decrease in particle size of ball clay and kaolin increased the coefficient of thermal diffusivity while the coefficient of thermal diffusivity decreased with an increase in particle size of sawdust.

Phonphuak. (2013) studied how charcoal addition affected the thermal properties of fired clay bricks. All samples were fired at 950 °C. The study indicated that there was a 10 wt. % reduction in the density of fired clay bricks based on the percentage of charcoal added to the clay. Porosity increases as the percentage of charcoal is increased in the clay body. The study results thus, presented that the thermal conductivity decreases since it is dependent on the density and porosity of fired clay bricks. Porous bricks have voids that slow down heat flow thus lowering thermal conductivity as well as thermal diffusivity.

Phonphuak *et al.*(2020), investigated how the incorporation of sawdust wastes into clay affected and thermal conductivity of fired bricks. The bricks of dimensions 14 cm by 6.5 cm by 4.0 cm were hand molded from the mixture of clay with sawdust wastes substituting clay with 0 %, 2.5 %, 5 %, 7.5 %, and 10 % by weight of sawdust wastes. The bricks were then fired at 900 °C, 1000 °C, and 1100 °C at a soaking time of 30 minutes. The fired samples were then tested for thermal conductivity and bulk density. The results pointed out that; the bulk density decreased by 10 wt.% of sawdust wastes. The thermal conductivity of the bricks fired at 1000 °C was found to decrease from 0.47 to 0.22 Wm⁻¹K⁻¹ for the addition of 2.5-10

wt.% by weight of sawdust wastes. This, therefore, implies that the brick samples obtained in this study provide good thermal insulation when used in building walls.

Muñoz *et al.* (2020), incorporated paper pulp residues (PPR) into the kaolinite red clay in a bid to reduce resource depletion and improve the brick's thermal conductivity and apparent porosity. The samples this study used were made from mixtures of kaolinite red clay with paper pulp wastes. The percentage of PPR replacement of clay is 0 %, 2.5 %, 7.5 %, 12.5 %, and 17.5 %. The samples were molded by extrusion, dried and all fired at 900 °C following industrial procedure. The fired samples were tested and the study found out that the PPR wastes added increased the apparent porosity by about 17% due to pores developed after burning off of PPR, thus resulting in reduced density (from 1.76-1.39 gdm⁻³) and also in the process lowering its thermal conductivity from 0.53 Wm⁻¹K⁻¹ to 0.41 Wm⁻¹K⁻¹ for samples from 0 % to 17.5 %.

Görhan & Şimşek, (2013), investigated the impact of adding rice husk into clay for bricks production, on the porosity and thermal Conductivity of the fired bricks. The rice husk substitution by volume into brick raw materials was 5%, 10%, and 15%. The clay and the rice husks were mixed with the plasticity water ranging from 18.2%-29.8% for the mixture to achieve homogeneity. The mixture was compacted at 0.6 MPa in a mold of size 40 mm by 70 mm by 50 mm, and dried in an electric oven at 55°C for 12 hours. The samples were then fired at a rate of 2.5 °C/min for temperatures of 700, 800, 900, and 1000 °C for a soaking time of 1 hour and allowed to cool to room temperature. Thermal conductivity was then tested using shotherm QTM D2 using hot-wire method. The results showed that the bricks samples without rice husk presented the highest values of thermal conductivity at all firing temperatures. However, the bricks with coarse rice husk added presented the lowest thermal conductivity than that of ground rice husk fired at 900°C. The temperature of 900°C was reported as the optimal temperature of the study. While the optimal percentage of the rice husk in the composite bricks was found to be 10%. Although the 15% rice husk addition presented bricks with lower values of thermal conductivity than 10%, those were fragile and thus not suitable for construction.

Ahmad *et al.* (2017), also investigated how the coal and wheat husk addition into clay impacted the thermal properties of fired clay bricks. The percentage replacement of clay by the additive is 5 wt.%, 10 wt.%, 15 wt.%, 20 wt.%, 30 wt.%, 40 wt.%, 50 wt.%. These were mixed and hand-molded in the steel mold of dimensions 20 mm by 15 mm by 10 mm

rectangular bars. They were then dried at 110 °C for over 4 hours and they were eventually fired to 1000 °C at 10 °C/min for 1 hour. Cooled samples were then tested for Thermal conductivity (k) and coefficient of thermal diffusivity. Thermal conductivity was then observed to drop by 27 % for 5 wt.% coal addition to 68 % for 50 wt.% coal addition whereas there was a decrease of 48 % for 5 wt.% of wheat to 92 % for 50 wt.% of wheat husks addition. The coefficient of thermal diffusivity was observed to decrease by 15-60 % for 5 wt. %-50 wt. % of coal added and also decreased by 49-92 % for 5-50 wt. % of wheat husks added. Thus, low thermal diffusivity means the fired bricks can be used as a thermal insulator in the building. Clay bricks microstructures showed that samples with a higher proportion of additives presented larger voids/pores than bricks without additives fired at 1000 °C. This is because the organic wastes got burnt during firing leaving large voids in the brick samples. In conclusion, the study found that clay bricks containing 5-15 wt. % of the additives presented better results which does not compromise the building standards.

Srisuwan, (2018), investigated the addition of grass (GA), coconut husk (CH), and sugar bagasse (SB) into the clay for the potential production of the fired bricks of improved thermal insulation. The clay content replaced by the wastes was 0 wt. %, 2.5 wt. %, 5.0 wt. %, 7.5 wt. % of the total mixture. The water of about 20-25 % by weight of the mixture was used in the mixture to attain plasticity and homogeneity. The pastes were molded to a size of 140 mm by 65 mm by 40 mm, then air dried for 2 hours and later dried at 105±5 °C in an electric lab oven for 24 hours. All the samples were then fired at 1000 °C for 1 hour and cooled naturally. Fired samples were tested and the outcome was that the pore sizes increase as the waste content increases as revealed by the scanning electron microscope (SEM) micrograph. An increase in porosity also implied an increase in shrinkage and water absorption thus resulting in a decrease in the bulk density of the samples. From the results, thermal conductivity varied from 0.45 Wm⁻¹K⁻¹ to 0.21 Wm⁻¹K⁻¹. Based on the GA, CH, and SB contents from 2.5 wt. % to 7.5 wt. %, the results showed that agricultural wastes are potentially sustainable building materials that can improve thermal insulation.

Bories *et al.* (2015), studied the impact of the addition of wheat straw, sunflower seed cake, and olive stone flour into clay, on the thermal performance of fired clay bricks. The clay replacement content by the additives was 4 wt. % and 8 wt. % of the mixture. The mixture was mixed in a rolling mill to achieve homogeneity and water of up to 22.2 wt. % was added to achieve plasticity. The pastes were then molded by extrusion in a mold of a dimension of 175 mm by 79 mm by 17 mm and dried up to 105 °C in the lab oven. The samples were fired

at 920 °C at a soaking time of 1 hour in the lab furnace and later allowed to cool. The test and measurements carried out revealed that; for all the samples. The optimal content of the sunflower seed cake was found to be 4 wt.% at the lowest grinding. Thus, giving bricks the thermal conductivity of 0.2 Wm⁻¹K⁻¹ which is a 61 % decrease in the thermal conductivity of the samples.

Adazabra *et al.* (2018), studied the potential addition of spent shea wastes (SSW) into clay bricks production. This was in a bid to improve the properties of the bricks such as apparent porosity, fired density, nature of pores, and thermal conductivity of the bricks. In this study clay material was replaced with 0 wt.%, 5 wt.%, 10 wt.%, 15 wt.%, and 20 wt.% of the SSW. The bricks samples were made through uniaxial pressing at 25 MPa into a dimension of 90 mm by 35 mm by 30 mm. They were then dried and fired up to 500 °C at a rate of 2 °C/min for 2 hours and further heated to the desired firing temperatures of 900 °C -1000 °C at a holding temperature of 1 hour. The tested technological properties indicated that the fired density decreased with the increase in the content of SSW. The micropores were seen to be large and many with the increase in the SSW content. However, with an increase in the firing temperature, the micropores were seen to reduce in size and numbers as revealed by scanning electron microscope micrograph. The thermal conductivity was observed to lower more and more with the increase in the SSW content but slightly increased at 1200 °C due to glassy phase formation. Therefore, it was found that the spent Shea wastes could subsequently be used to enhance firing, improve the fluxing properties of the raw materials, and produce lightweight bricks with improved thermal insulation properties.

Demir, (2008), studied the potential use of organic residues; sawdust, tobacco residues, and grass in clay brick production while reporting their effects on the technological properties of the brick's porosity, and density. In this case, clay was mixed with each of these organic residues in increasing amounts of 0 %, 2.5 %, 5 %, and 10 % in wt. All the samples were fired at 900 °C in an electric furnace for 60 minutes. The study found that the organic residue addition resulted in larger open pores in the brick body for the increasing amount of residue while still maintaining acceptable mechanical properties. The nature of organic residue was found not to cause any extrusion problems. The higher residue content required high moisture content thus ensuring the right plasticity. The insulation capacity of the bricks was found to rise with the rise in porosity as the content of organic residue increased. This implies that there is low thermal conductivity and diffusivity in the building.

Makaka. (2014), studied the addition of fly ash into clay for brick production, to improve its thermal conductivity. Bricks of different clay and fly ash mixing proportions were molded. Results indicate that thermal conductivity decreases with an increase in fly ash. A mixture ratio of 50 % fly ash to 50 % clay by volume produced the best brick with the lowest thermal conductivity. These properties significantly impacted the thermal performance of the house. The mean indoor temperature swing was found to be 11 °C.

Aeslina Abdul Kadir & Sarani. (2012), reviewed the different clay bricks made with several different waste additives like rubber, limestone dust, processed waste tea, fly ash, and polystyrene. The varying contents in the range of 1%-50% were made. The results showed that there was a decrease in thermal conductivity due to an increase in porosity after firing. The bulk density of the brick was also observed to drop with the increase in the content of the waste. An estimated energy-saving potential of up to 40% was recorded and thus these wastes were found to be economically available and cheap.

Thus, from the reviewed papers above, there are so many additives looked at by different scientists but local distillery waste was not looked at in fired clay bricks. Therefore, there was a need to explore and find out if the use of local distillery waste in clay brick production may improve the thermal properties of the building bricks. In the same way, may add more information to the knowledge world.

2.4 Effect of firing temperature on clay bricks properties

Johari *et al.* (2010), studied the effects of firing temperature on the porosity of the brick. The samples were fired from 800 °C to 1250 °C at a soaking time of 1 hour. The optimum firing temperature was found to be 1200 °C. The porosity reduced from 39.33 % to 5.87 % when sintered from 1000 °C to 1250 °C. This implies that thermal conduction in the bricks increased at very high temperatures of 1000 °C and above.

Karaman *et al.* (2006b), determined the effects of firing time and temperature on the densities of clay bricks and found that the density decreases with an increase in firing temperature for bricks fired at 700-1100 °C. Thus, the decrease in the physical properties like fired density and water absorption indicates the likeness of improved thermal performance of the bricks.

Drive, Centennial Park, (2006), stated that firing is categorized into five general stages: (1) final drying (evaporating free water); (2) dehydration; (3) oxidation; (4) vitrification; and (5) flashing or reduction firing. All except flashing are associated with a rise in temperatures in

the kiln. Although the actual temperatures will differ with clay or shale, final drying occurs at about 204 °C. Dehydration which is the elimination of water molecules from clay occurs from about 149 °C to 982 °C since this varies from one clay material to another. Oxidation is the breakdown from 538 °C to 982 °C and vitrification from 871 °C to 1316 °C. The dehydration process which occurs between 30 °C – 200 °C contributes 2 % of porosity, dihydroxylation between the temps of 450 °C – 600 °C contributes 2 %, while decarbonization of calcium carbonate which occurs between 650 °C – 850 °C, resulting in a 3 % by volume porosity formation. When sintering increases from 850-1100 °C, the porosity is decreased by 2 % by volume (Nigay *et al.*, 2019). Porosity is known to increase as waste addition increases whereas the density decreases. The pores formed make it difficult for heat to diffuse through the bricks. This gives low thermal conductivity and hence good thermal comfort due to low values of the coefficient of thermal diffusivity of the building material (Nigay *et al.*, 2019) Vitrification is a gradual process during which the materials in clay that melt most easily do so to form a glassy phase in the clay body (Karaman *et al.*, 2006a). They dissolve and fill in the spaces between the more refractory particles. The molten materials aid in further melting as well as compacting and strengthening the clay body. During the firing of clay products, the liquid phase starts at a temperature above 940 °C and this process helps to eliminate the voids and pores by filling in the openings inside. High porosity thus, caused high thermal resistance in the samples with high waste percentages (Mc Conville & Lee, 2005).

According to Coronado *et al.* (2020), The firing process is paramount in the making of ceramic products with controlled properties. The materials undergo permanent structural changes under fire to reach the final desired ceramics product. The firing conditions, firing temperature, firing rate, and soaking time in the kiln or furnace all differ for different materials used. composition and mineralogy of the clay greatly affect the temperature at which the liquid phase is created. Vitrification in most cases starts at 950 °C and is completed at about 1350 °C. However, lime, and alkalis which are fluxing agents tend to lower the initial melting temperatures of the clay product, in the process increasing the amount of liquid phase formed. Thus, reducing energy consumption during firing. This is particularly true when the clays are calcareous.

Therefore, the values of various thermal properties are observed to vary with the temperature variation and different additive mixture rations. The goal of this study was to determine the value of the bricks' coefficient of thermal diffusivity, which would enhance the thermal insulation of building walls, using local distillery waste added into clay.

CHAPTER THREE: METHODOLOGY OF THE STUDY

3.1 Introduction

This chapter includes Research design, materials and samples preparation, and determination of the coefficient of thermal diffusivity of the samples through the measurements of thermal conductivity, specific heat capacity, and the density of the samples prepared.

3.2 Research Design

The research involved exploratory and experimental research designs. The exploratory research design was used to discover a suitable clay deposit site used by the locals in the Ayole swamp. The exploratory design was also used to find out, the ingredients used in the local brew and to identify large quantity waste producers. The design was used as well to identify suitable equipment for sample preparations and measurements. The exploratory design was to support the experimental design. The experimental design was based on the sample preparation, materials characterization, tests, and measurements of thermal conductivity, specific heat capacity, and density of the samples.

3.3 Materials and sample preparation

3.3.1 Collection of clay samples

The clay soil was obtained from Ayole swamp in Aduku sub-county. Convenience sampling was used (this is a non-probability sampling method where units are selected for inclusion in the sample because they are the easiest for the researcher to access). It was dug using a hand hoe from one pit at a depth of 0.5 meters. This is because at half a meter depth clay is less mixed with sand compared with higher depth. The clay was then spread under the sun to dry in free air for seven (7) days, to drive off moisture content. The dry clay was then packed in polyethylene bags awaiting sample preparation.

3.3.2 Collection of Local Distillery Waste

Local distillery waste was obtained from a local brewery distiller in Aduku town council, Kwania district in Northern Uganda.

Local distillery waste is a by-product of the distillation of a crude brew. This crude brew is produced from cassava. In this case, cassava flour is mixed with water to form a solid slurry. This slurry is fermented for a minimum of 5 days (this is to effectively detoxify the product), roasted, and dried. The dried roasted slurry is then dissolved in water, followed by the

addition of local yeast made from sorghum flour. The yeast helps in fermentation and this takes 7-10 days. The period of 7-10 days enables the starch and sugar to break down until it is ready for distillation. The resulting products of this stage are ethanol and carbon dioxide. After distillation what remains in the distillation container, most commonly pots or distillation barrels, is the local distillery brewery waste. The local brewery waste used in this study was then collected in containers. This waste was poured on an open dry cemented surface to sun dry under strong sunshine for at least 14 days, to obtain dried hard solid lumps. These lumps were then packed in bags for further processing in the project laboratory.

3.3.3 Characterization of Clay and Local Distillery Waste.

Chemical analysis by weight percentage of the clay and local distillery waste was performed using the Energy Dispersive X-ray Fluorescence (EDXRF) spectroscopy Epsilon 1. It is an integrated EDXRF analyzer made of, an in-built computer, touch screen, analytical software, and a spectrometer. When using the EDXRF Spectrometer, the general chemical composition of both clay and the local distillery wastes was determined through; the use of pressed powder pellets for checking various analytical runs as well as calibration. In this study, pressed pellets were obtained when the clay and local distillery waste lumps respectively, were milled and then sieved using less than 63 μ m mesh size. This is because the accuracy of the data depended on the nature(fineness) of the particle size.

EDXRF uses an X-ray as a polychromatic source and has a sample holder, a detector, and several electronic components for energy discrimination as illustrated in Figure 3.1. The pellets were then placed on the sample holder and closed. The sample's name code (in this case CS for clay soil and DW for local distillery wastes) is entered and the measure button is pushed for measurement to commence. After about 10 minutes when the measurements were done the analytic results were then displayed on the screen. The Omani software which is an advanced standard less analysis software was used to analyze the sample. The final compound by weight percentages was then printed.

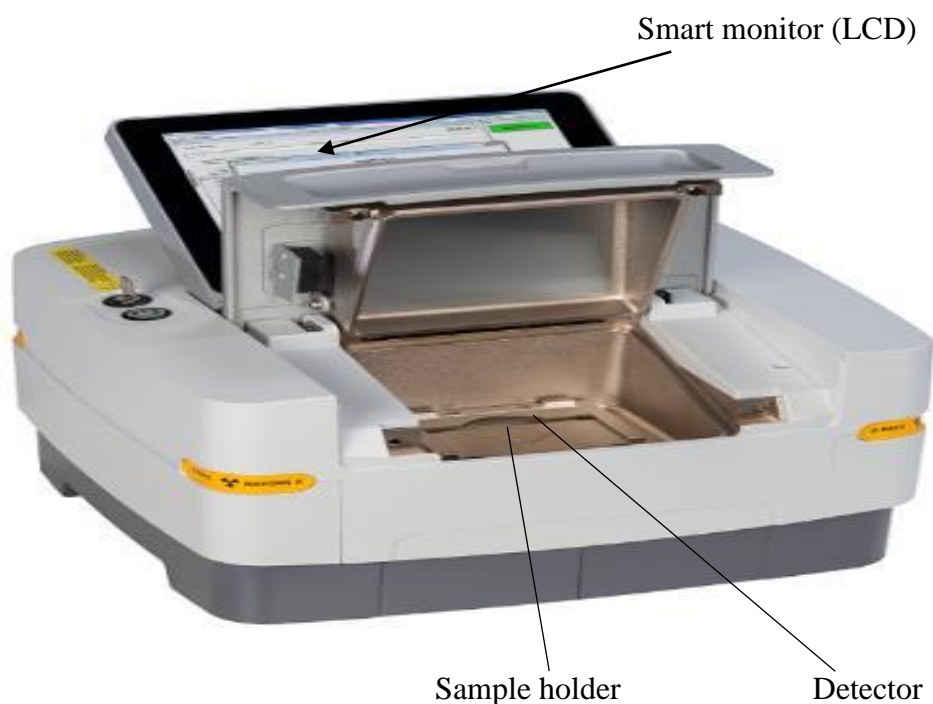


Figure 3.1: Photograph of Epsilon 1 (EDXRF) spectroscopy.

3.3.4 Preparation of Samples

Clay was dissolved completely by pouring water into it and allowing it to stay for seven days. This purposely helped to separate the clay material from unwanted particles like roots, stones, and sand. When the clay was dissolved in the water, the stones and sand being denser than water settled at the bottom of the container, and the roots and grasses being less dense floated on the water's surface. The roots and grasses were then easily removed from the surface by a metallic strainer. The stones and the sand were removed by gently pouring off the dissolved clay into another container leaving the stones and sand stuck at the bottom of the container. Clay was then spread on a polyester clothing material on an open surface. This allowed water to escape from the clay to the ground and in the process harden the clay into solid lumps. These Clay lumps were eventually dried at 105 °C for 24 hours in an electric oven, to drive out all moisture content or chemically combined water in the clay. The fully dried clay was then pounded in a metallic mortar using a metallic pestle into powder form. The clay powder was then sieved with the help of a mechanical test sieve shaker for 10 minutes; to separate a mixture of granulated materials into fractions and each fraction contained particles of similar dimensions. In the process, Clay particles of a maximum size of 125 μm were obtained when clay was passed through a sieve of size 125 μm .

Local brewery waste-dried solid lumps were also fully dried in an electric oven at 110 °C for 24 hours, to eliminate moisture from solid lumps. It was then pounded and shaken in a sieve of size 215 µm. This was just to aid in uniform mixing it with clay this is because Local distillery waste is soluble in water. The clay and the local distillery waste powders were then carefully aerated and manually mixed by rotating the mixture in a cylindrical metal pale connected to a manually rolling bearing for 15 minutes. This was to ensure the homogeneity of the mixture. Finally, the water of 16 percent by weight of the mixture was added to each mixture until a uniform consistency of the paste was achieved. The ratios in Table 3.1 were based on earlier studies and also experimental trial and error, whereby samples with waste replacement above 20 wt.% presented some cracks during drying and firing.

Table 3.2: Proportions of clay and local distillery wastes mixed for sample making.

Samples	Clay (wt.%)	Local distillery wastes (wt.%)
S _A	80	20
S _B	84	16
S _C	88	12
S _D	92	08
S _E	96	04
S _F	100	00

The pastes were then sealed in polythene bags for 24 hours (maturation process). This was to achieve the maximum possible plasticity and aid further homogeneity as water flows in the voids. The subsequent pastes from the above mixtures in their different proportions as in Table 3.1, were then transferred to a steel mold of dimension 7.8 cm by 4.0 cm by 3.0 cm, which is about 75 % less the dimension of a standard brick. A constant weight of 15 kg was placed on the pastes in the mold for 5 minutes. This was to help samples to have better strengths and improved homogeneity in the specimens. The pastes were then trimmed to fit in the dimensions of the mold. The wet samples were thereafter released from the molds and kept for 48 hours under room temperature until they hardened. This was to minimize shrinkage and cracking during drying. They were then dried in a laboratory electric oven at

110 °C for 4 hours, this was to get rid-off water from the samples. Four (4) replicates of each of the dried samples, S_A, S_B, S_C, S_D, S_E, S_F (Figure 3.2(a)), were then fired to the different temperatures of 600 °C, 700 °C, 800 °C, 900 °C, 1000 °C, 1100 °C at a rate of 10 °C/min for one hour in the furnace (Ahmad *et al.*, 2017). The furnace was eventually turned off and the samples were allowed to cool to room temperature before they were removed for testing and measurements. Figure 3.2 (b)-(d) shows brick samples at different temperatures. Other samples can be found in Appendix O. Average values of replicates for each sample at different temperatures were used in this study.

a)



(b)



c)

d)

Figure 3.2: (a) Unfired bricks, (b) Samples fired at 1100 °C, (c) Samples fired at 900 °C, (d) Samples fired at 600 °C.

3.4 Experimental measurements

3.4.1 Thermal Conductivity, k

The thermal conductivity was determined by Quick Thermal Conductivity Meter (QTM-500), with sensor probe (PD-11), constantan heater wire, and chromel-alumel thermocouple (Figure.3.3). This uses the transient technique (non-steady state) or hot wire method which helps in the study of conduction of heat through the samples. The probe was first connected to the QTM system. The power supply to the system was then turned on and the heater current of the system was set at 1 A. Thermal conductivity was also set as the parameter to be measured. The equipment was then allowed to attain thermal equilibrium, this took about 15 minutes. Afterwards, the sample brick was inserted inside the probe case and the sensor probe was then placed on the brick in the case. In the process, heat from the probe heater is sent to the sample until a thermal equilibrium is attained for the whole setup. Thermal conductivity measurement was then finalized when the “enter button” was pressed. A graph of temperature against time was generated within 60 seconds and the thermal conductivity value was obtained from the graph through an inbuilt processor of QTM 500 meter and the value was then digitally displayed on the LCD screen.

Sensor probe

QTM system



Figure 3.3: Kyoto electronic Quick thermal conductivity meter QTM 500.

3.4.2 Measurement of Specific Heat Capacity

The method of mixtures was used to obtain the specific heat capacity of the samples. Since this is the most readily available, fairly accurate, cheap, and easy-to-use method, it does not require expertise to operate. The sample brick was crushed into smaller particles and its mass, m_s was measured using an electronic weighing balance. It was then placed in a wooden top-sealed glass test tube fitted with a digital thermometer. The set was then placed in a beaker of boiling water which was on a heating mantle. While the sample was being heated, the mass, m_c of the empty calorimeter was determined and recorded. The calorimeter was approximately half filled with cold water and weighed and the mass of water, m_w was then determined by getting the mass difference. The temperature of the water in the calorimeter θ_1 , was measured. The calorimeter was then placed back into its insulated jacket. After heating the brick sample for 20 minutes, the temperature of the sample, θ_3 was read from the digital thermometer. The hot sample was fast but gently transferred into the water in the calorimeter and stirred continuously. The temperature reading was taken at the time interval of 60 seconds until thermal equilibrium was reached. The temperature of the mixture at equilibrium, θ_2 was determined. The specific heat capacity of the sample was then calculated from equation 3.1. The heat lost by the solid in cooling from θ_3 to θ_2 is equal to heat gain by water and the calorimeter in warming from θ_1 to θ_2 .

$$c = \frac{(m_w c_w + m_c c_c)(\theta_2 - \theta_1)}{m_s(\theta_3 - \theta_2)}, \quad (3.1)$$

where c_w is the specific heat capacity of water, c_c is the specific heat capacity of the calorimeter.

3.4.3 Determination of the density, ρ

The density of the sample was computed using Equation 3.2

$$\text{Density, } \rho = \frac{\text{mass}}{\text{volume}}, \quad (3.2)$$

the mass of the sample was measured using the electronic beam balance. The volume was obtained from the dimensions of the sample measured using a vernier caliper and a meter rule. Volume was then obtained from equation 3.3.

$$\text{Volume} = \text{Length} \times \text{Width} \times \text{Height} \quad (3.3)$$

3.4.4 Measurement of Coefficient of thermal diffusivity of the samples

The coefficient of thermal diffusivity was calculated using Fourier's law of solids given by equation 3.4 (ASTM,2019).

$$\alpha = \frac{k}{\rho c}, \quad (3.4)$$

where α is the coefficient of thermal diffusivity and its SI unit is ($\text{m}^2 \text{s}^{-1}$), k is the thermal conductivity, ρ is density, and c is specific heat capacity.

3.5 Statistical analysis of the results

F-test statistics/distributions from Microsoft Excel was used to check whether the firing temperatures and the mixture proportion of clay and local distillery wastes significantly affected the coefficient of thermal diffusivity of the samples. The F-test is appropriate for determining if there is a statistical difference between or among samples. If the calculated F-value is found to be less than the critical F-value obtained from the statistical table, then it is concluded that there is no significant statistical difference between or among the mean, and if the calculated value is greater than the critical value then there is a significant difference.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Chemical composition of Ayole swamp's clay and local distillery waste

The chemical composition of Ayole swamp's clay and local distillery waste used in this study were determined. Table 4.1 shows the chemical composition of clay and local distillery waste in weight percentage. However, this percentage did not sum up to 100% for both clay and local distillery waste. This is because some oxides were not determined due to financial constraints and also due to loss on ignition.

Table 4.2: Chemical composition of Ayole clay and local distillery wastes.

Chemical compounds	Ayole swamp clay(wt.%)	Local distillery wastes(wt.%)
SiO ₂	55.6	4.7
Al ₂ O ₃	10.4	-
K ₂ O	1.7	5.7
CaO	0.3	1.4
TiO ₂	2.5	0.3
MgO	1.7	1.6
NiO	16.6	1.0
Fe ₂ O ₃	2.0	13.6
As ₂ O ₃	0.9	29.9
SO ₃	0.04	0.5
Loss on ignition (L.O. I)	8.26	41.3

There was an abundance of silica (SiO₂) in the clay used in this study thus predicting good thermal properties in the end bricks. Silica is majorly used in the ceramics industry in the areas of thermal insulation, and refractories, especially in the furnace, thus silica has good thermal shock resistance above 650 °C. This is because SiO₂ is known to contribute to a high level of porosity in the clay product. This lowers its thermal conductivity and in this case, improves the thermal insulation of bricks and enhances the energy efficiency of buildings (Adazabra *et al.*, 2018). The clay used in this study showed a significant presence of SiO₂. This was within the required range for ceramics production, which compares with that of silica which is in the range (50-60 wt.%). Thus the silica in this sample should have led to the creation of pores during drying and firing. This thus reduces the heat flow across the samples

thus lowering the coefficient of thermal diffusivity of the samples. Alumina in the clay was in the required range of 10-20 wt.%. Since it is chemically inert, alumina is a filler used in bricks. As it mixes with other fluxing oxides to raise melting temperatures, it exhibits high heat capacity and high thermal conductivity. Consequently, it is possible to create thermally abrasive materials with it. According to Muñoz Velasco et al. (2014), in this instance, a larger alumina concentration boosts the samples' strength and thermal diffusivity. The absence of alumina in the local distillery waste suggests that the waste counteracts the quantity of alumina in the clay. Consequently, the samples' thermal diffusivity value is fairly affected, particularly at lower temperatures.

The fluxing oxides of the raw materials used to make the samples, such as CaO, K₂O, and MgO, were found in clay and local distillery waste at somewhat greater concentrations of 3.4 and 8.7 weight percentages, respectively. When the temperature rises during vitrification, these high values subsequently boost the creation of mullites and cristobalities, which leads to a higher density due to glassy phase formation. Increased thermal conduction between the samples results from this. This enhances the thermal diffusivity throughout the sample (Afaf zarkik, 2015 & Liew *et al.*, 2004). The high percentage of iron III oxide, (Fe₂O₃) (13.6 wt. %) in the local distillery wastes could have been the reason behind the highly reddish colour of the bricks fired at higher temperatures from 900-1100 °C. Similarly, TiO₂ contributes to the attractive colour of the sample. NiO is low fire glaze due to its refractory nature, it will produce green, brown, and grey glazes but more commonly modify or grey the colors obtained from other coloring oxides by combination. This is normally used in small amounts. This was observed on bricks fired from 700-900 °C which appeared greyish in colour. However, samples fired at 1100 °C, showed black cores this is basically because of overheating.

The clay used in this study was non-calcareous. Calcareous clay contains more than 6 wt.% of CaO, this is a product of calcium carbonate and non-calcareous clay contains less than 6 wt.% (Elert *et al.*, 2004). This means the cementing effect of calcium oxide will be low thus, formed pores are not filled up fully during fusion. These unfilled pores will lower heat flow across the samples, implying a decrease in the coefficient of thermal diffusivity of the samples.

The total weight percentage concentration of K₂O, Fe₂O₃, CaO MgO, and TiO₂ in this clay is 8.2 wt. % as in Table 4.1. this means that this clay is a low refractory clay since 8.2 wt.%

gives no significance difference with 9 wt.%. This is because according to Kazmi *et al.*, (2016), clay is considered as low refractory if the total concentration of K_2O , Fe_2O_3 , CaO , MgO & TiO_2 is higher than 9 wt.% and it is a high refractory clay material if the concentration is less than 9 wt.%. Therefore, the clay used in this study is non-calcareous and a low refractory clay thus suitable for improved thermal brick-making in the construction industry.

4.2 Coefficient of thermal diffusivity

The coefficient of thermal diffusivity in this study was obtained through the measurement of; thermal conductivity, specific heat capacity, and the density of fired samples. Thus, the effect of firing temperatures and the local brewery waste proportion on the coefficient of thermal diffusivity is discussed in relation to Figures 4.1 and 4.2. Figure 4.1 shows the dependence of the coefficient of thermal diffusivity on firing temperature for fixed sample ratio and Figure 4.2 shows the graphical relation of the coefficient of thermal diffusivity with the variation of mixture content.

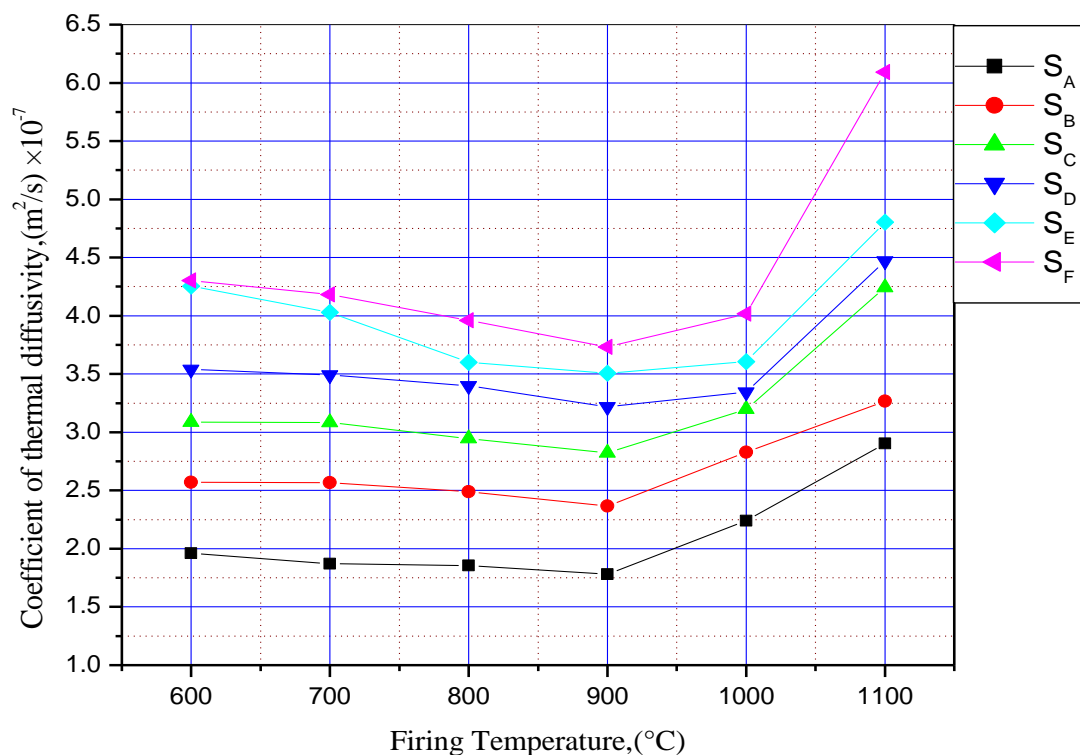


Figure 4.1: Variation of coefficient of thermal diffusivity with firing temperatures for all the samples.

Figure 4.1, clearly shows that the value of the coefficient of thermal diffusivity decreased for all sample proportions, from firing temperature of 600 °C – 900 °C. However, for all samples fired at 900 °C, values of the coefficient of thermal diffusivity remained lowest compared to the rest of the firing temperatures. The figure also shows a rise in the values of the coefficient of thermal diffusivity for the temperature above 900 °C. Samples fired at 1100 °C all presented very high values of coefficient of thermal diffusivity in this study. These trends could be because, the organic matter in the wastes burnt out within these temperature ranges. Also, some of the clay particles and minerals such as CaO (0.3 wt.%), K₂O (1.7 wt.%), and MgO (1.7 wt.%) could have melted, thereby filling the voids and increasing the ease with which heat moves through the sample. As the temperature is increased further, more clay particles are melted, greatly reducing the voids and as a consequence, a huge increase in the coefficient of thermal diffusivity. This is because the local distillery wastes additive to the clay burnt out during firing processes leaving pores or voids within the brick sample. This in turn produced less denser bricks compared to the bricks made of clay alone. However, the control bricks which had 0 wt.% of the wastes (S_F), showed the highest values of coefficient of thermal diffusivity at all firing temperatures as seen from the trends of the curves on the graph. This could be because, the organic matter in the clay burnt out fast leaving few and small pores, compared to those with wastes with large and numerous pores (Bwayo & Obwoya, 2014).

At 600 °C, the organic wastes are burnt but incompletely, thus probably creating smaller and fewer voids or pores in the brick product. As the firing temperature was increased to 700 °C, 800 °C and 900 °C, more organic matter in the wastes was expected to burn until it was complete at 900 °C, creating larger voids or airspace in the bricks sample. These voids retard the transfer of heat easily in the bricks thus, as the thermal conduction is low in this case and so the coefficient of thermal diffusivity lowers, as seen in Figure 4.1. According to Peterson. (2020), clays have some carbon, sulfur, and organic matter content, and all of these burn between 300 °C to 800 °C. The chemically combined water in clay is driven off at temperatures between 350-800 °C, this is because clay structurally consists of a molecule of alumina and two molecules of silica (silicon dioxide) which are all bonded to two molecules of water. Therefore, this accounts for about 14 wt. % of water in the clay, which must be dried fully for a good product to come out. In the process of driving this water, other unburnt carbon is burnt completely. This leaves air space which makes thermal diffusion very low. Clay starts sticking together but when still porous and not yet vitrified this occurs at 945 °C

which is called bisque firing (Peterson, 2020). This explains possibly why there is an increasing trend in the values of the coefficient of thermal diffusivity for samples fired above 900 °C. The coefficient of thermal diffusivity remained highest for the control brick, S_F, fired at all temperatures. This is perhaps because, the clay soil organic matter and mineral constituents burn leaving few and smaller pores compared to the sample with the local distillery waste additives (Ozturk *et al.*, 2019). Figure 4.1 shows how a particular mixture proportion of clay and local distillery waste affects the coefficient of thermal diffusivity at varying firing temperatures.

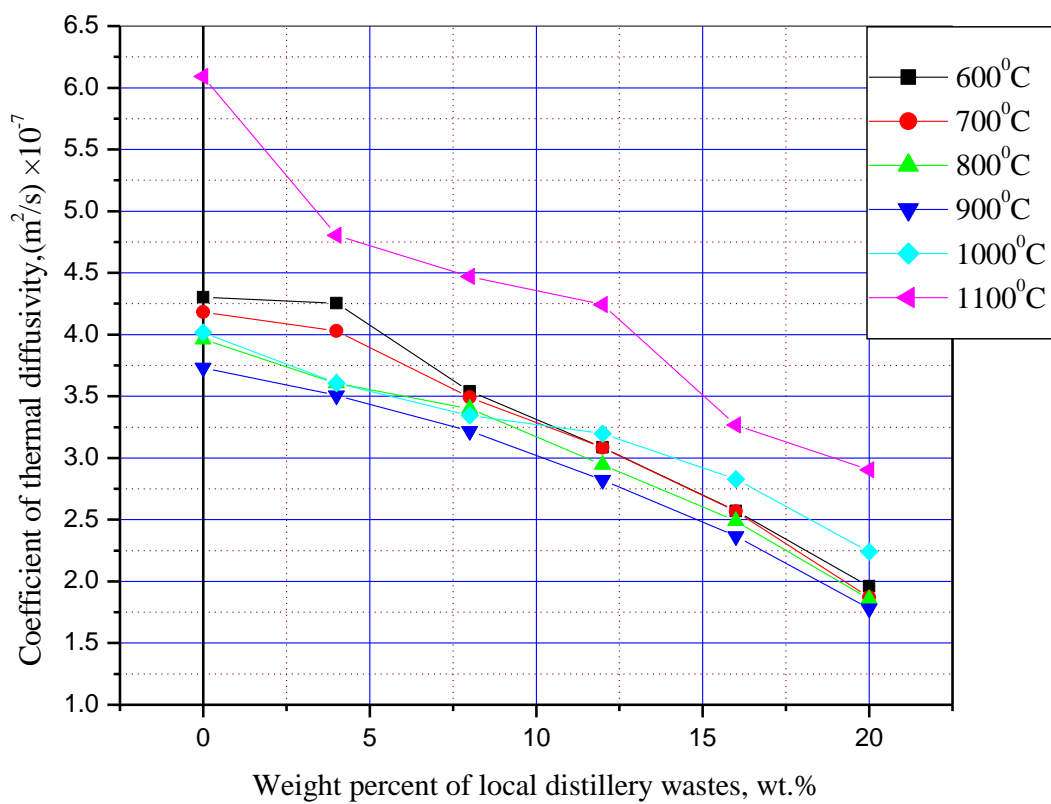


Figure 4.2: Variation of coefficient of thermal diffusivity with weight percentage of local distillery wastes in clay bricks at different temperatures.

Figure 4.2, shows a decrease in the coefficient of thermal diffusivity value as the content of local distillery waste in clay was increased. The lowest value of the coefficient of thermal diffusivity of brick samples without the local distillery wastes is $3.732 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$. This represents a decrease of 52 % for a sample with 20 wt. %, to 06 % for a sample with 4 wt. % of local distillery wastes added to the clay and fired at 900 °C. This implies that there was a great drop in values of the coefficient of thermal diffusivity when waste was added. This is

because at this temperature organic material will have fully burnt out leaving larger voids thus lowering the conduction of heat. Samples fired at 1100 °C all exhibited higher values of coefficient of thermal diffusivity compared to the rest at other firing temperatures, with the highest value being that of the control brick at $6.082 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$. This represents a decrease of 52 % for samples with 20 wt. %, to 21 % for samples with 4 wt. % of local distillery wastes added to clay. This could have been contributed by the melting of clay oxides thus filling in voids which helps in the easy flow of heat across the sample. The dehydration process which occurs between 30 °C – 200 °C contributes 2 % of porosity, dihydroxylation between the temps of 450 °C – 600 °C contributes 2 %, while decarbonization of calcium carbonate which occurs between 650 °C – 850 °C, resulting in a 3 % by volume porosity formation. When sintering increases from 850-1100 °C, the porosity is decreased by 2 % by volume (Nigay *et al.* 2019). Porosity is known to increase as waste addition increases whereas the density decreases. The pores formed make it difficult for heat to diffuse through the bricks. This gives low thermal conductivity and hence good thermal comfort due to low values of the coefficient of thermal diffusivity of the building material (Nigay *et al.* 2019). Thermal diffusion is slightly increased at higher sintering temperatures (950-1100 °C), basically because the vitrification process starts at about 950 °C. Vitrification is a gradual process during which the materials in clay that melt most easily do so to form a glassy phase in the clay body (Karaman *et al.* 2006a). They dissolve and fill in the spaces between the more refractory particles. The molten materials and fluxing oxides like calcium, and sodium aid in further melting as well as compacting and strengthening the clay body. During the firing of clay products, the liquid phase starts at a temperature above 940 °C and this process helps to eliminate the voids and pores by filling in the openings inside. High porosity thus, caused high thermal resistance in the samples with high waste percentages (McConville & Lee, 2005)

From Figure 4.1, the temperature of 900 °C, presented all the samples with very low values of coefficient of thermal diffusivity for each respective mixture proportions. Samples with 20 wt.% wastes (S_A) showed the lowest values for this study $1.781 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$, S_B (samples with 16 wt.% clay replacement) having $2.365 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$, S_C (samples with 12 wt.% of clay replacement by local distillery wastes) having $2.823 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$. From these three proportions, sample S_A has the lowest value of the coefficient of thermal diffusivity and could have been the most suitable. However, it showed a high level of brittleness and was physically fragile, especially for those samples fired at 600 °C and 1100 °C. Thus, the

coefficient of thermal diffusivity values for the sample with clay was replaced by 16 wt. % (S_B) was chosen as the optimal value for this study. This is because S_A presented the lowest value of the coefficient of thermal diffusivity but is fragile to be used for construction whereas S_B was physically suitable just like any brick made of clay only (Perrin & Rigal, 2014). The temperature of 900 °C is the optimal temperature reported as suitable by this study as in Figure 4.2. This study conclusively indicated that the local distillery waste addition in clay substantially affected the coefficient of thermal diffusivity values. Thus, sample S_B is recommended by this study as the most suitable for construction and thus for enhancing thermal comfort. Low values of thermal diffusivity are required to, minimize heat conduction through materials.

The observed low values of the coefficient of thermal diffusivity obtained in this study subsequently, indicate that the investigated samples are suitable as insulators for walling purposes (Bwayo & Obwoya, 2014). Figure 4.2 shows how the variation of clay and local distillery waste mixture at a particular fixed temperature affects the values of the coefficient of thermal diffusivity.

4.3 F-test Statistical analysis of the samples

The F-statistics analysis was performed both at 99 % and 95 % confidence limit to show whether firing temperature and the mixture proportion affected the coefficient of thermal diffusivity of the samples. The results are summarized in the various tables in Appendix A to Q.

From Appendix H to M, firing from 600-1100 °C affected the mean values for thermal diffusivity of all 6 sample proportions significantly. This is because, at 95 % and 99 % confidence intervals, the calculated F-values from Table 4.2 are all higher than the critical F-values obtained ($F_{\alpha=0.01} = 4.25$ and $F_{\alpha=0.05} = 2.77$). This implies that there is a significant difference in the mean values of the coefficient of thermal diffusivity of all the samples fired at different temperatures, thus firing temperatures greatly affected the thermal diffusivity values of the different samples. This is graphically shown in Figure 4.1.

Table 4.2: Calculated F- values at different firing temperatures.

Firing temperature(°C)	600	700	800	900	1000	1100
Calculated F-	84.54	129.61	255.29	113.50	65.78	101.67

values						
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From Appendix N to S, different proportions of the samples S_A , S_B , S_C , S_D , S_E , S_F presented significant differences in the mean values of thermal diffusivity at different firing temperatures.

Table 4.3: Calculated F- values for different samples.

Samples	S_A	S_B	S_C	S_D	S_E	S_F
Calculated F-values	16.32	13.30	79.07	32.54	26.08	188.75

The calculated F-values from Table 4.3 for the S_A , S_B , S_C , S_D , S_E , S_F , all being higher than the critical F-values ($F_{\alpha=0.01} = 4.25$ and $F_{\alpha=0.05} = 2.77$). Thus, the mixture proportions significantly affected the mean values of thermal diffusivity. This is according to the trends of the curves in Figure 4.2. The high values of the calculated F-values compared to the critical values show that there is a great difference in the mean values of the coefficient of thermal diffusivity. Thus, the two independent variables of firing temperature and mixture ratios of clay and local distillery waste greatly affected the coefficient of thermal diffusivity of the samples.

From the analysis performed the highest (Maximum) value of thermal diffusivity is $6.08 \pm 0.185 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$ at both 95 % and 99 % confidence intervals. This also presented a maximum error of $2.18 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$ and $4.21 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$ at 95 % and 99 % confidence limits respectively. This occurred at 1100 °C for sample S_F . Thus at a 95 % confidence limit the error margin is minimized compared to the 99 % confidence interval.

The minimum value for thermal diffusivity of this study is $1.78 \pm 0.16 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$ at both 99 % and 95 % confidence intervals. It presented a maximum error of $1.59 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$ and $8.22 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$ at 99 % and 95 % confidence limits respectively. This occurs at 900 °C for sample S_A . Sample S_A would be most suitable but were physically fragile which does not suit

building construction. Thus, the immediate low value is considered which is in the range $2.36 \pm 0.0699 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$ for samples at both 99 % and 95 % confidence intervals. This presented maximum errors of $1.59 \times 10^{-8} \text{ m}^2 \text{ s}^{-1}$ and $5.55 \times 10^{-9} \text{ m}^2 \text{ s}^{-1}$ at 99 % and 95 % confidence intervals respectively. The ranges of maximum and minimum values above are to cater for experimental errors that arose during various experimental steps. The minimum values were a result of multiple pores formed in the sample whereas the maximum values occurred because of the reduced pores for samples firing at 1100°C .

4.4 Comparison of coefficient of thermal diffusivity of samples

From the results in section 4.3, this study focused on the clay and local distillery waste mixtures of different proportions (samples S_A, S_B, S_C, S_D, S_E) but also considered clay alone without any local distillery wastes (sample S_F). Therefore, the comparison of the coefficient of thermal diffusivity of these samples was discussed. Figure 4.3 is the linear fitted curves of a plot of the coefficient of thermal diffusivity against the weight percentage of local distillery waste fired at different temperatures.

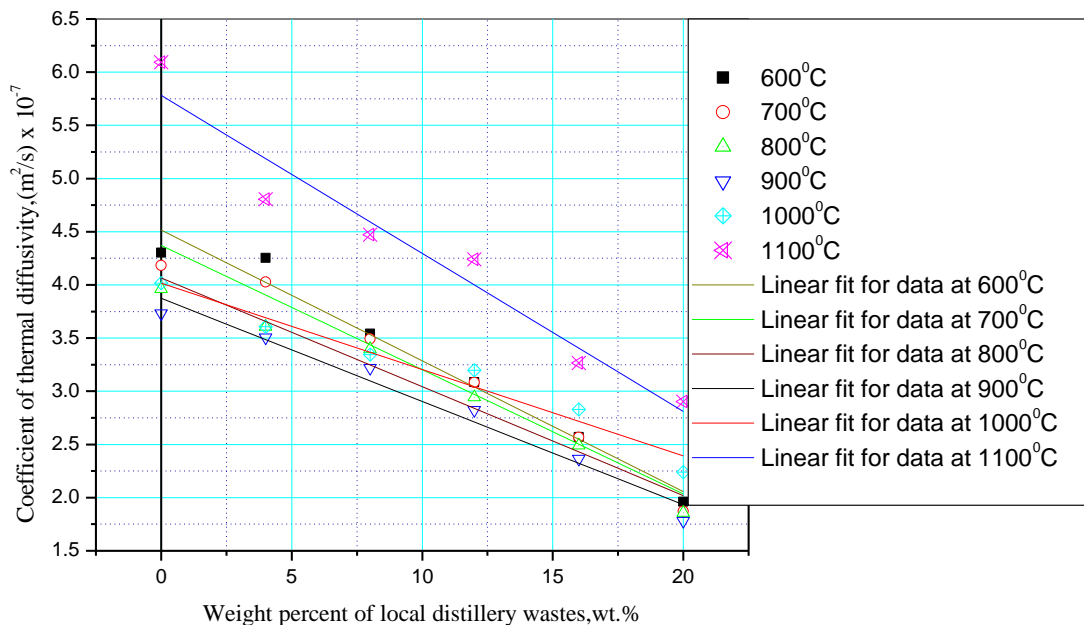


Figure 4.3: Variation of coefficient of thermal diffusivity with weight percentage of local distillery wastes at all firing temperatures.

Figure 4.3, showed linear variations with negative slopes. This implies that the coefficient of thermal diffusivity is inversely proportional to the weight percentage of the local distillery

wastes added to clay in the brick samples. Here the coefficient of thermal diffusivity decreases as the local distillery wastes added to clay increase in weight percentage. From the linear fitted curves in Figure 4.3, most points are close to the line of best fit as indicated by high values of adjusted R-squared values which are on average 0.96 for firing temperatures of 600, 700, 800, and 900 °C but these values dropped from 0.956 to 0.934 at 1000 °C and 1100 °C respectively as in single graphs from Appendix A to F. Thus, predicting the high level of significance in the relationship between the coefficient of thermal diffusivity and weight percent of local distillery wastes. All these showed behaviors of the coefficient of thermal diffusivity for all mixture proportions while showing the highest values across all the temperatures for sample S_F. Therefore, the other mixture proportions are then compared to clay bricks (0 wt.% of local distillery wastes added to clay).

At 1100 °C, the coefficient of thermal diffusivity at S_F (0 wt. % local distillery wastes) presented the highest value of $6.092 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$. This is evident with a very slight drop in the value of adjusted R-squared value of 0.934 as in Appendix F. Comparing S_F value with other mixture proportions presented a decrease in the values of coefficient of thermal diffusivity by 52.4 %, 46.4 %, 30.4 %, 26.6 % and 21.1 % for S_A, S_B, S_C, S_D, and S_E respectively. From Figure 4.3, the value of the coefficient of thermal diffusivity of S_F is the highest. This is basically because of vitrification which is almost the maximum. In this case, the pores formed in the bricks are filled during glassy formation during firing thus there is increased heat conduction across the samples (Johari *et al.*, 2010). The different samples appear to be a little far away from the line of best fit except for S_A

At 600 °C, the value of the coefficient of thermal diffusivity of S_F was $4.303 \times 10^{-7} \text{ m}^2/\text{s}$ and this was the second highest in this study. In comparison with other mixture proportions, it presented a decrease in the coefficient of thermal diffusivity by 54.4%, 40.3%, 28.3%, 17.7%, and 1.1% for S_A, S_B, S_C, S_D, and S_E respectively. From Figure 4.3 there is a linear negative slope with most points very close to the best line of fit as indicated by the adjusted R-squared value (0.96825) of the plots to the linear fit as in Appendix A(a). From the fitted curves, S_F and S_E were slightly deviating from the line of best fit as all the other proportions were very close to the line. This implies that the addition of local distillery waste to clay lowered the coefficient of thermal diffusivity as its content increased as in section 4.3. (Muñoz *et al.*, 2014). This temperature also presented the lowest decrease of 1.1% compared to the rest. this is basically because at this temperature organic matter in the clay burns but incompletely leaving quite a few voids in the samples thus this is still a high diffusion of heat across bricks.

At 700 °C, the coefficient of thermal diffusivity of S_F was $4.185 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$ and this is the third highest value in this study. This when compared with other mixture ratios, presented a decrease of 55.3%, 38.7%, 26.3%, 16.5%, and 3.7% in the values of coefficient of thermal diffusivity for S_A, S_B, S_C, S_D, and S_E respectively regarding S_F at 700 °C as in Appendix B. This temperature presented the highest percentage decrease of 55.3 % compared to samples at all the other temperatures.

At 1000 °C, the value of the coefficient of thermal diffusivity of S_F obtained was $4.016 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$. This is a reference value, compared with the other samples presenting a decrease of 44 %, 29.6 %, 20.4 %, 16.7 %, and 10.2 % for samples S_A, S_B, S_C, S_D, and S_E respectively as in

Appendix E. The difference in the percentage regarding S_F reduced across all samples probably because of the formation of a glassy phase in the samples at this temperature.

At 800 °C, the value of the coefficient of thermal diffusivity of S_F was $3.961 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$. This compared with the other samples presenting a decrease of 53%, 37.1%, 25.7%, 15%, and 2.9% in the values of coefficient of thermal diffusivity of samples S_A , S_B , S_C , S_D , and S_E respectively. This is also predicted by the closeness of most of the points to the line of best fit as confirmed by R^2 - Value (0.9677). Thus at 800 °C the values of coefficient of thermal diffusivity were consistently affected by the local distillery waste addition into the clay.

At 900 °C, the value of the coefficient of thermal diffusivity of S_F is $3.722 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$ and is the record lowest in this study. When compared with other samples it presented a decrease of 52.3%, 36.6%, 24.4%, 13.7%, and 6.0% in the values of the coefficient of thermal diffusivity of samples S_A , S_B , S_C , S_D , and S_E respectively. Figure 4.3, showed that the values of thermal diffusivity were within close range for most mixture ratios except for 20 wt. % which was lowest at $1.781 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$. This is indicated by a high value adjusted R-squared value of 0.96616 and a lower standard deviation of $1.3534 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$. This accounted for a 52.3% decrease in the value of the coefficient of thermal diffusivity of S_A . However, throughout this temperature all the samples (S_B , S_C , S_D , S_E , and S_F) presented lower values of coefficient of thermal diffusivity compared with the rest at other temperatures as in Appendix D. This is probably because at this temperature all organic matter in clay alone and mineral combustion will have occurred resulting into formation of larger voids in the sample thus, restricting thermal flow through the samples.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The building wall material's thermal properties play a great role in the determination of the thermal behaviors of buildings. In this case, therefore, the choice of bricks with a low coefficient of thermal diffusivity is considered paramount in coming up with low-energy consumption buildings that maintain thermal comfort in buildings. Heat flows faster through materials with higher values of coefficient of thermal diffusivity and slowly through materials with low coefficient of thermal diffusivity. This study thus, investigated the impact of variation in firing temperatures and the addition of local distillery wastes in clay bricks production, on the coefficient of thermal diffusivity of the resulting bricks. The coefficient of thermal diffusivity decreased as the content of local distillery waste in clay was increased for brick production. Sample S_A at 900 °C presented the lowest value of the coefficient of thermal diffusivity of $1.78 \times 10^{-7} m^2 s^{-1}$. This low value is desired for this study but this sample was physically fragile and thus was not a sustainable material for building strong walls. The 16 wt. % local distillery waste replacement presented $2.297 \times 10^{-7} m^2 s^{-1}$ at 900 °C as the second-best value of the coefficient of thermal diffusivity. This was not physically fragile or brittle just like samples made of clay only. Thus, 16 wt. % local distillery waste replacement was reported as the most suitable local distillery waste content considered in the study. The coefficient of thermal diffusivity decreased as the temperature increased but increased at temperatures above 900 °C. All samples presented low values of the coefficient of thermal diffusivity at 900 °C. Thus, an optimum value of $2.297 \times 10^{-7} m^2 s^{-1}$ at 900 °C was exhibited by samples with 16 wt.% local distillery waste replacement of clay. This value is below the accepted standard of $5.61 \times 10^{-7} m^2 s^{-1}$. Therefore, local distillery waste is suitable for use in clay as a material that can improve the thermal insulation of building walls.

5.2 Recommendations

This study recommends the following areas for further studies;

- i) There is a need to explore the potential of many other organic wastes such as maize cob ash, local distillery waste ash, and cassava peelings in a bid to provide a sustainable solution to the building energy demands and curb environmental pollution. Thus, addressing the sustainable development goal (06) of clean water and sanitation.
- ii) More studies should be done in the future to confirm the effect of the use of local distillery wastes in brick production on; mechanical strength, this would help in optimizing the firing temperature and also the local distillery waste's weight percent replacement in clay.
- iii) The scanning electron microscope(SEM) analysis should be done to ascertain the microstructure of the brick samples this would help in the scientific conclusion based on pore sizes and numbers and carry out an XRD analysis for mineralogy analysis which will help in knowing the particular clay in use.

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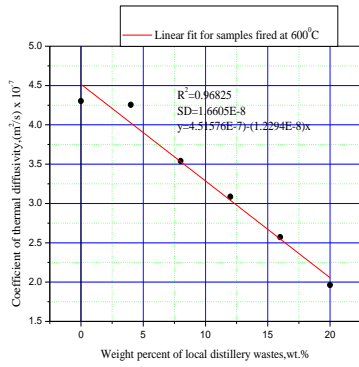
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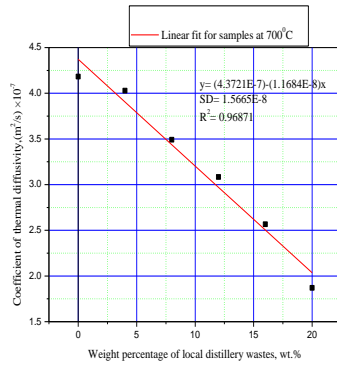
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APPENDICES

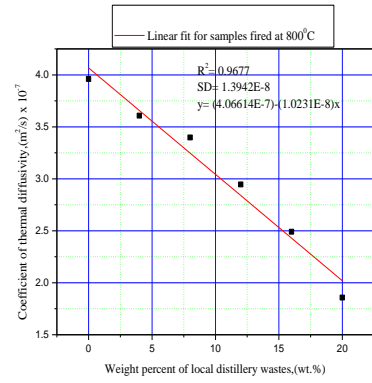
Appendix A: Variation of coefficient of thermal diffusivity with weight percent of local distillery wastes fired at (a) 600 °C, (b) 700 °C, (c) 800 °C, (d) 900 °C, (e) 1000 °C, (f) 1100 °C



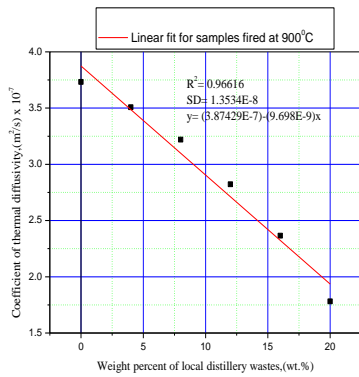
(a)



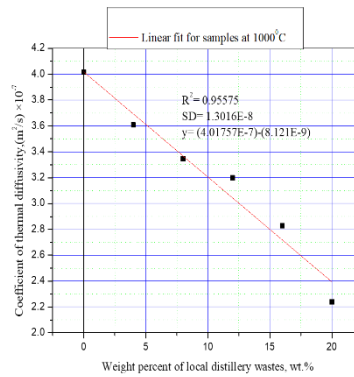
(b)



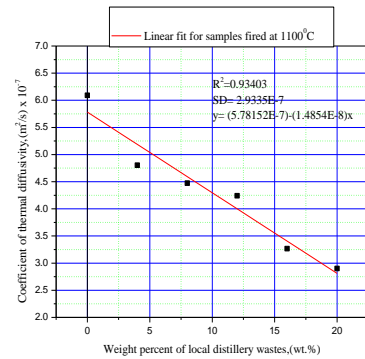
(c)



(d)



(e)



(f)

Appendix B-1: The average values of the coefficient of thermal diffusivity at different temperatures for sample S_A

Temperature, Θ (°C)	Coefficient of thermal diffusivity, α (m ² /s) $\times 10^{-7}$
600	1.962
700	1.870
800	1.857
900	1.781
1000	2.239
1100	2.902

Appendix B-2: The average values of the coefficient of thermal diffusivity at different temperatures for sample S_B.

Temperature, θ (°C)	Coefficient of thermal diffusivity, α (m ² /s) $\times 10^{-7}$
600	2.571
700	2.566
800	2.490
900	2.365
1000	2.828
1100	3.266

Appendix B-3: The average values coefficient of thermal diffusivity at different temperatures for sample S_C

Temperature, θ (°C)	Coefficient of thermal diffusivity, α (m ² /s) $\times 10^{-7}$
600	3.086
700	3.084
800	2.945
900	2.823
1000	3.198
1100	4.241

Appendix B-4: The average values coefficient of thermal diffusivity at different temperatures for sample S_D

Temperature, θ (°C)	Coefficient of thermal diffusivity, α (m ² /s) $\times 10^{-7}$
600	3.541
700	3.491
800	3.398
900	3.219
1000	3.345
1100	4.472

Appendix B-5: The average values coefficient of thermal diffusivity at different temperatures for sample S_E

Temperature, Θ (°C)	Coefficient of thermal diffusivity, α (m²/s) $\times 10^{-7}$
600	4.255
700	4.028
800	3.601
900	3.507
1000	3.607
1100	4.804

Appendix B-6: The average values coefficient of thermal diffusivity at different temperatures for sample S_F.

Temperature, θ (°C)	Coefficient of thermal diffusivity, α (m²/s) $\times 10^{-7}$
600	4.303
700	4.183
800	3.961
900	3.732
1000	4.016
1100	6.092

Appendix C: Data analysis for all samples fired at 600 °C.

	S_F	S_E	S_D	S_C	S_B	S_A
Mean	4.30E-07	4.26E-07	3.54E-07	3.09E-07	2.57E-07	1.96E-07
Standard deviation	4.27E-09	3.73E-08	1.43E-08	5.98E-09	2.73E-08	8.86E-09
Max. error at $\alpha=0.01$	9.70E-09	8.47E-08	3.24E-08	1.36E-08	6.19E-08	2.01E-08
Max. error at $\alpha=0.05$	5.03E-09	4.39E-08	1.68E-08	7.04E-09	3.21E-08	1.04E-08

F-value = 84.54

Critical F-Value, $F_{\alpha=0.01} = 4.25$ and $F_{\alpha=0.05} = 2.77$

Appendix D: Data analysis for all samples fired at 700 °C

	S_F	S_E	S_D	S_C	S_B	S_A
Mean	4.18E-07	4.03E-07	3.49E-07	3.08E-07	2.57E-07	1.87E-07
Standard deviation	1.49E-08	1.52E-08	1.7E-08	8.7E-09	9.94E-09	2.32E-08
Max. error at $\alpha=0.01$	3.38E-08	3.44E-08	3.86E-08	1.97E-08	2.26E-08	5.26E-08
Max. error at $\alpha=0.05$	1.75E-08	1.78E-08	2E-08	1.02E-08	1.17E-08	2.73E-08

F=129.61,

Appendix E: Data analysis for all samples fired at 800 °C

	S_F	S_E	S_D	S_C	S_B	S_A
Mean	3.96E-07	3.6E-07	3.4E-07	2.94E-07	2.49E-07	1.86E-07
Standard deviation	1.42E-08	2.77E-09	5.04E-09	1.3E-08	4.72E-09	1.18E-08
Max. error at $\alpha=0.01$	3.21E-08	6.29E-09	1.14E-08	2.95E-08	1.07E-08	2.69E-08
Max. error at $\alpha=0.05$	1.67E-08	3.26E-09	5.93E-09	1.53E-08	5.55E-09	1.39E-08

F=255.29

Appendix F: Data analysis for all samples fired at 900 °C

	S_F	S_E	S_D	S_C	S_B	S_A
Mean	3.74E-07	3.51E-07	3.22E-07	2.82E-07	2.36E-07	1.78E-07
Standard deviation	5.59E-09	1.34E-08	1.84E-08	1.7E-08	6.99E-09	1.6E-08
Max. error at $\alpha=0.01$	1.27E-08	3.04E-08	4.17E-08	3.86E-08	1.59E-08	3.64E-08
Max. error at $\alpha=0.05$	6.57E-09	1.58E-08	2.16E-08	2E-08	8.22E-09	1.89E-08

F= 113.50

Appendix G: Data analysis for all samples fired at 1000 °C

	S_F	S_E	S_D	S_C	S_B	S_A
Mean	4.02E-07	3.61E-07	3.34E-07	3.2E-07	2.83E-07	2.24E-07
Standard deviation	1.08E-08	1.86E-08	2.02E-08	9.22E-09	1.93E-08	8.34E-09
Max. error at $\alpha=0.01$	2.46E-08	4.23E-08	4.58E-08	2.09E-08	4.38E-08	1.89E-08
Max. error at $\alpha=0.05$	1.28E-08	2.19E-08	2.37E-08	1.08E-08	2.27E-08	9.82E-09

F=65.78

Appendix H: Data analysis results for all samples fired at 1100 °C

Sample	S_F	S_E	S_D	S_C	S_B	S_A
Mean	6.08E-07	4.80E-07	4.47E-07	4.24E-07	3.35E-07	2.9E-07
Standard deviation	1.85E-08	1.30E-08	1.57E-08	1.19E-08	2.27E-08	3.94E-08
Max. error at $\alpha=0.01$	4.21E-08	2.94E-08	3.56E-08	2.70E-08	5.15E-08	8.94E-08
Max. error at $\alpha=0.05$	2.18E-08	1.52E-08	1.85E-08	1.40E-08	2.67E-08	4.63E-08

F= 101.67

Appendix I: Data analysis results for sample SA fired at different temperatures

Temperature	600 °C	700°C	800°C	900°C	1000°C	1100°C
Mean	1.96E-07	1.87E-07	1.86E-07	1.78E-07	2.24E-07	2.9E-07
Standard deviation	8.86E-09	2.32E-08	1.18E-08	1.6E-08	8.34E-09	3.94E-08
Max. error at $\alpha=0.01$	2.01E-08	5.26E-08	2.69E-08	3.64E-08	1.89E-08	8.94E-08
Max. error at $\alpha=0.05$	1.04E-08	2.73E-08	1.39E-08	1.89E-08	9.82E-09	4.63E-08

F=16.32

Appendix J: Data analysis results for sample SB fired at different temperatures

Temperature	600 °C	700°C	800°C	900°C	1000°C	1100°C
Mean	2.57E-07	2.57E-07	2.49E-07	2.36E-07	2.83E-07	3.35E-07
Standard deviation	2.73E-08	9.94E-09	4.72E-09	6.99E-09	1.93E-08	2.27E-08
Max. error at $\alpha=0.01$	6.19E-08	2.26E-08	1.07E-08	1.59E-08	4.38E-08	5.15E-08
Max. error at $\alpha=0.05$	3.21E-08	1.17E-08	5.55E-09	8.22E-09	2.27E-08	2.67E-08

F = 13.30

Appendix K: Data analysis results for sample SC fired at different temperatures

Temperature	600 °C	700 °C	800 °C	900 °C	1000 °C	1100 °C
Mean	3.09E-07	3.08E-07	2.95E-07	2.82E-07	3.20E-07	4.24E-07
Standard deviation	5.98E-09	8.70E-09	1.30E-08	1.70E-08	9.22E-09	1.19E-08
Max. error at $\alpha=0.01$	1.36E-08	1.97E-08	2.95E-08	3.86E-08	2.09E-08	2.70E-08
Max. error at $\alpha=0.05$	7.04E-09	1.02E-08	1.53E-08	2.00E-08	1.08E-08	1.40E-08

F=79.07

Appendix L: Data analysis results for sample S_D fired at different temperatures.

Temperature	600 °C	700 °C	800 °C	900 °C	1000 °C	1100 °C
Mean	3.54E-07	3.49E-07	3.40E-07	3.22E-07	3.34E-07	4.47E-07
Standard deviation	1.43E-08	1.70E-08	5.04E-09	1.84E-08	2.02E-08	1.57E-08
Max. error at $\alpha=0.01$	3.24E-08	3.86E-08	1.15E-08	4.17E-08	4.58E-08	3.56E-08
Max. error at $\alpha=0.05$	1.68E-08	2.00E-08	5.93E-09	2.16E-08	2.37E-08	1.85E-08

F=32.54

Appendix M: Data analysis results for sample S_E fired at different temperatures.

Temperature	600 °C	700°C	800°C	900°C	1000°C	1100°C
Mean	4.26E-07	4.03E-07	3.60E-07	3.51E-07	3.61E-07	4.80E-07
Standard deviation	3.73E-08	1.52E-08	2.77E-09	1.34E-08	1.86E-08	1.30E-08
Max. error at $\alpha=0.01$	8.47E-08	3.44E-08	6.29E-09	3.04E-08	4.23E-08	2.94E-08
Max. error at $\alpha=0.05$	4.39E-08	1.78E-08	3.26E-09	1.58E-08	2.19E-08	1.52E-08

F=26.08

Appendix N: Data analysis results for sample S_F fired at different temperatures.

Temperature	600 °C	700°C	800°C	900°C	1000°C	1100°C
Mean	4.30E-07	4.18E-07	3.96E-07	3.73E-07	4.02E-07	6.08E-07
Standard deviation	4.27E-09	1.49E-08	1.42E-08	5.59E-09	1.08E-08	1.85E-08
Max. error at $\alpha=0.01$	9.70E-09	3.38E-08	3.22E-08	1.27E-08	2.46E-08	4.21E-08
Max. error at $\alpha=0.05$	5.03E-09	1.75E-08	1.67E-08	6.57E-09	1.28E-08	2.18E-08

F=188.75

Appendix O: Pictures showing some of the fired samples at (a) 1000 °C,(b) 800 °C, (c) 700 °C



a)



(b)



(c)

Appendix P: Relevant expressions used in F-test statistical analysis

$$i) \quad SST = \sum_{i=1}^k x_i^2 - \frac{T^2}{kn},$$

Where T is the total for the whole data, $x_i^2 = x^2$, k =number of columns, n=number of rows.

$$ii) \quad SSTr = \frac{1}{n} \sum_{i=1}^k T_i^2 - \frac{T^2}{kn}$$

$T_i^2 = \text{square of individual sums}$

T= sum of all the data

$$iii) \quad SSE = (SST - SST_r)$$

$$iv) \quad MSTr = \frac{SSTr}{k-1}$$

$$v) \quad MSE = \frac{SSE}{k(n-1)}$$

$$vi) \quad F = \frac{MSTr}{MSE}$$

$$vii) \quad \text{Max error} = \frac{k\sigma}{\sqrt{n}}$$

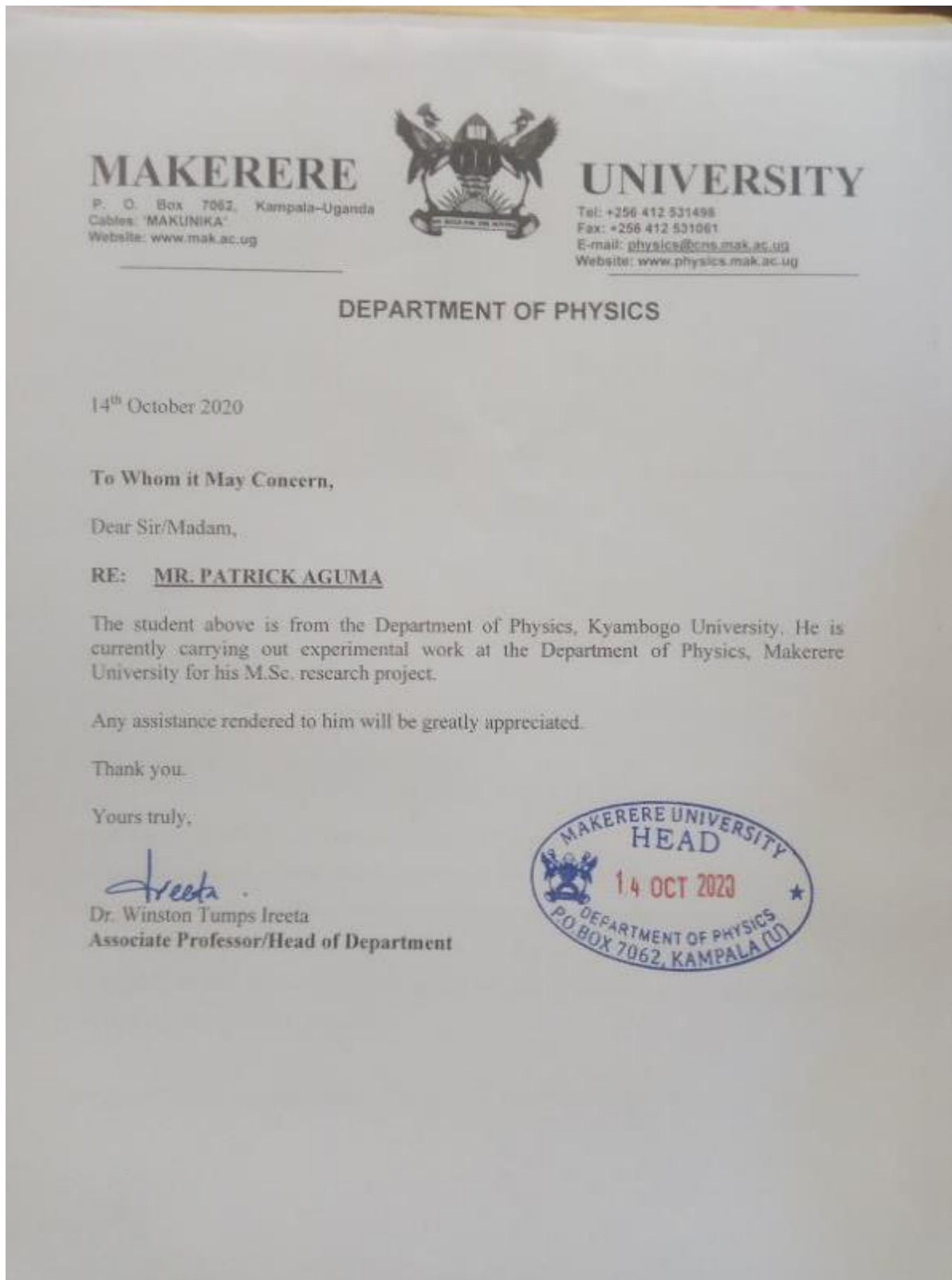
Where $k_{\alpha=0.01}=4.541$, $k_{\alpha=0.05}=2.353$,

$\sigma = \text{standard deviation}$

n= number of rows

Standard deviation, average values, and summation of the data were done following the formulae in Microsoft Excel when the data is entered.

Appendix Q: Some relevant documents



KYAMBOGO UNIVERSITY

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P. O. BOX 1, KYAMBOGO – KAMPALA, UGANDA
DEPARTMENT OF PHYSICS

October 10, 2020

The Head, Department of Physics
School of Natural Sciences
Makerere University
Kampala - Uganda

Dear Sir/Madam

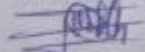
RE: INTRODUCTORY LETTER FOR AGUMA PATRICK

This is to introduce the above named person who is a student in the Department of Physics, Kyambogo University, pursuing a Master of Science in Physics degree. Aguma is currently doing his research in the field of material science, working on clay and distillery waste.

The purpose of this communication is to request you to allow him use your facility and equipment to carry out his investigation.

Your positive response will be highly appreciated.

Yours faithfully,



Dr. Okullo Michael
H.O.D, Physics