EVALUATION OF THE PERFORMANCE OF A HYBRID ELECTRO-THERMOPHILIC SILVER CYPRINID DRYER

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Declaration

I declare that, to the best of my knowledge, this Research Thesis is original, and that the work contained herein has not been conducted and/or submitted for any research undertaking in any other degree award to any other university before.

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Dedication

I dedicate this project in a special way to dear parents, my late father Hon. Deng Alier Mading Majok (Former Minister of Youth and Sports—Jonglei State, South Sudan) and my mother Martha Kuir Ajieth, for nurturing me to be a man I am today and for the encouragement and financial support they gave me throughout my pursue of lower and higher education. Special word of appreciation goes to my lovely colleagues; friends; my brothers and sisters; my stepmothers and members of my immediate extended family, the family of the late Paramount Chief Mading Majok, for their persistent support and encouragement throughout my academic life. To my lovely wife, Caren Namwendua Iyadi and three sons (Mading, Alier and Kuol), who encouraged me to apply for the Program and who have been the source of my hard work and for their endurance and caring sacrifices they have made.

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Abstract

Bulk fish production continues to suffer losses from poor preservation and more specifically inadequate drying in many rural communities. Mechanized dehydration is preferred over the traditional open-air sun drying, but it is energy intensive and costly. Minimizing energy losses and enhancing process efficiency remain key priorities for dryer design. In this study, the energy saving potential of integrating compostable insulations in the dryer walls was evaluated under the assumption that supplementing process heat with energy from thermophilic decomposition of the biodegradable materials could enhance efficiency. The influence of thermophilic energy on drying processes remains undocumented. Therefore, the main objective of this study was to evaluate the performance of a hybrid electro-thermophilic Silver Cyprinid fish dryer and more specifically: to characterize the batch-drying of silver cyprinid, establish appropriate models for the drying kinetics, and assess the energy saving potential of the integrated thermophilic energy vis-a-viz the pure electric system. A dryer with a total load capacity of ten trays each having a capacity of 800g was used. Fresh Silver Cyprinid fish samples were exposed to both pure electric and hybrid electro-thermophilic drying at temperature settings of 40°C and 60°C, each exposed to both low (1.4 m/s) and high (2.8 m/s) air velocities—the samples were also subjected to one, five and ten-tray experiments. Drying curves were determined gravimetrically and Graph Expert™ software applied to model the drying kinetics. Analysis of the results showed drying entirely in the falling rate period with drying times ranging between 8 and 20 hrs for a moisture content reduction from 85.37 to 8.57 %wb, across all experiments. Air velocity, temperature and tray settings had substantive impact for complete drying of the sample in both pure electric drying and hybrid electro-thermophilic drying. Lower drying times and higher drying rates were experienced at lower tray settings. A number of mathematical drying models (Newton, Page, Henderson & Babis, Logarithm, Lewis, and Diffusion model) were investigated and the Lewis model was superior with highest value of coefficient of determination (R^2) of 0.988213 and lowest values of standard error of estimate (SEE) of 0.001913. The specific energy consumption SEC, at the 5-tray setting, was 8.05 kJ/kg of water removed for pure electric drying compared to 7.54 kJ/kg of water removed for the hybrid electro-thermophilic drying, representing an energy saving of close to 24%. The results demonstrated the untapped potential of integrating beneficial thermophilic bacteria into walls to enhance the performance and lower costs in food drying systems. In this study thermophilic energy was applied only to one side of the dryer. Further research is recommended on commercial applicability of the prototype and to establish the influence of integrating this energy into all the walls of the dryer. Use of different compostable materials, besides the cow manure and shredded maize stover applied in this study, should also be investigated.

Keywords: *Thermophilic process, indirect drying, forced convection, Silver Cyprinid, thin-layer drying, mathematical model*

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Nomenclature/ List of Abbreviations

ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
CHRS	Compost heat recovery system
DR	Drying rate
EAC	East African Community
EF	Modeling efficiency factor
EMC	Equilibrium Moisture Content
MC	Moisture content
MR	Moisture ratio
MRR	Moisture removal rate
OGT	Optimal growth temperature
RMSE	Root mean square error
SDG	Sustainable Development Goals
SEC	Specific Energy Consumption
SEE	Standard error of estimate
wb	Wet basis

Subscripts

exp.	Experimental
pre.	Predicted
r^2	Coefficient of determination

CHAPTER ONE

1.0 Introduction

The world's population is about 7.5 billion people, and the number keeps increasing annually. This population survives mostly on agricultural and aquatic products as sources of energy; since most of these products are perishable, there is a need to maintain their nutritional content as well as keep them fresh in order to maintain their availability, more especially in developing countries where availability of fresh food is not assured throughout the year. As a result of unexpected skyrocketing costs of fresh food produce, there is an important need to preserve them and increase their shelf life and assure their availability for future consumption (Akinola & Bolaji, 2006).The availability of food in developing nations can be harnessed through reduction of post-harvest losses (Komolafe, et al., 2011). Chief among the products to be preserved is fish. Fish has a high protein content and nutritional value, and is regarded as an important constituent of the diet worldwide, as it presents about a tenth of the global protein (Komolafe, et al., 2011, and Abdulmajid,2015). Fish is also highly perishable making its availability for future consumption to be sustained through proper refrigeration or drying —in terms of delicacy, the dried fish is much more preferable because it presents unique taste and flavor for most consumers (Abdulmajid, 2015). Several other drying techniques are used to preserve fish, for example: salting, canning, roasting, osmotic drying, use of microwave drying , among others.

Among the varieties of fish is Silver Cyprinid (Rastrineobola Argentea); locally known as *omena* or *dagaa* in East Africa. It belongs to species of what is known as ray-finned fish which belongs to the family Cyprinidae of order Cypriniformes; in East Africa it is found in Lake Victoria, Lake Kyoga and River Nile (Yongo et al., 2016). In Kenya, L. Victoria is the chief source of fish and it is the only source of Silver Cyprinid that is consumed locally.

The fishing industry is a source of income and employment to over 2 million people in Kenya through different activities such as fishing, boat making and repair; supply of fish and other value-addition activities involving fish products. Silver Cyprinid is used as human feed; feed for poultry, piggery and fish farms; and industrially for production of pharmaceutical products as well as food supplements (EAC, 2016).

According to Akinola & Bolaji (2006), ensuring reduction of water level within fish to an extent where it is safe for storage for future use is the prime reason for drying of food produce. However, due to lack of adequate infrastructure (for example cold storage and chilling facilities) as well as technical expertise, fishermen, more especially in developing countries, resort to use of rudimentary methods like smoking, frying, salting, and sun drying that involve drying Silver Cyprinid on nets, grounds and on raised racks, which impact the quality of fish and greatly lead to post harvest losses (EAC,2016; Mumbo & Aila, 2014); Sengar et al., 2009). These processes take a lot of time besides being susceptible to compromising the quality of the fish through infestations by the insects such as flies leading to post harvest losses through degradation of fish. Besides the use of ineffective treatment methods, other factors such as delayed landing of the catch from fishing areas lead to post harvest loses in fish such as rotting, spoilage, loss in color and fish being swept by rain water—the solutions being sealing any leakages in the fishing vessels, fast delivery of the catch to the preservation point and proper handling of the catch. The major challenge for local fishermen, however, is bad weather especially prolonged rains (EAC, 2016).

Being an extremely perishable produce, its spoilage is attributed to rancidity as result of chemical oxidation, autolysis and actions of the bacteria present within the fish (Akinola & Bolaji, 2006). Fish begins to spoil immediately after its death—chemical and physical changes in various body parts of the fish, such as gills, eyes, slime and skin tissues, follow this degeneration (Omodara, 2012). This immediate spoilage of fish and preservation complexity demand for effective processing and drying techniques ranging from drying in solar dryers, sun dryers, and with mechanical dryers; smoking; salting, freezing; irradiation among other techniques.

Most fishermen in remote fishing sites dry their catch of Silver Cyprinid using open-air sun drying—this process is slow and it is hard to control drying process. This slow and intermittent nature of open-air sun drying has demanded for the development of solar cabinet dryer as a replacement to open-air sun drying worldwide (Emelue et al., 2015). Drying fish in a closed chamber enables the product to be concealed from dust and intruders (such as birds, insects and animals) that may otherwise lead to process losses besides compromising the quality of the dried fish (Sengar et al., 2009).

Biomass is also another form of renewable energy that provides energy in different forms: biomass inform of wood can be burnt to provide heat and light; some can host thermophilic bacteria that provide usable energy in form of heat, especially when sufficient physical conditions like optimum temperatures are provided. Amongst the utilization processes of biomass is application of the heat produced through decomposition of biomass in an aerobic-thermophilic process for various heating and drying needs such as drying of food produce.

Preservation techniques like the use of pure electric dryer have proven to be alternative and efficient drying technique—complementing with biomass source in the form of thermophilic facilitates reduction of the total electric energy consumption and subsequently the cost of buying the energy.

The major objective in a drying operation, according to Mumba (1994), is to provide optimum heat so as to achieve fine product quality at efficient overall expenditure of energy. In light of fish drying processes, this optimum temperature has to be sustained throughout the drying process—this call for the supplementary or a backup energy sources for the cases of intermittent sources of energy like solar and thermophilic energy with electric energy.

The use of thermophilic process, particularly for agricultural waste, provides two important utilizations processes of agricultural wastes: realization of waste-to-energy (WtE) process in which heat energy is recovered from biomass; and transformation of the waste into a nutrient-rich compost that can improve crop yield when used as manure. Drying time is a major factor in the drying processes of fish; this is determined by several factors like the size of the sample, air velocity, temperature intensity, among other factors. The temperature and air velocity intensities are the major factors influencing faster drying time. The moisture ratio of the samples decreases continually with drying time. Also, increase in air velocity of drying reduces the time required to reach given level of moisture ratio since the heat transfer Increases. In other words, at high air velocity the transfer of heat and mass is high and water loss is excessive. Higher air velocity leads to excessive water loss due to high mass and heat transfer (Kumar et al, 2017). The fishing industry provide a lot of fish which is used to satisfy the immediate and future human consumption requirements. The surplus fish may go to waste if not preserved very well.

1.1 Statement of the problem

According to EAC (2016) , 95% of the total fish in Kenya is caught in Lake Victoria. Silver Cyprinid, make up 62.9% of the total catch, according to Odongkara (2008) as cited by Mumbo & Aila (2014) in their study. According to EAC (2016), most fishers in Kenya experience a post-harvest loss of 65.9% of the total catch of Silver Cyprinid. *Omena* is a highly perishable food that easily goes bad, lose its nutritional content and develop some bad odor, if not attended to with uniform degree of consistency during drying process.

The most utilized technique of drying silver cyprinid in Sub-Saharan Africa is sun drying, since solar energy is available in abundance in the tropical regions. However, despite its inexhaustible nature, the use of solar energy as the sole provider of heat for food drying, especially perishable foods like fish, has its shortcomings, the solar insolation is only available from sunrise to sunset and its intensity is also affected by cloudy and rainy weather conditions, this renders the solar dryer inefficient during these periods. The catch from the lakes and other fishing water resources also do arrive late sometimes leading to shorter drying period during the day.

These shortcomings of the solar drying and other traditional drying techniques have demanded for investigation and application of other drying techniques, as sole dryers or as integrations of hybrid energy systems. Pure electric drying, biomass combustion to provide heat, geothermal energy drying, and solar energy drying are some of the methods that are used to dry fish. Drying using thermophilic energy is another method that has a prospect of drying food produce. Two or more of these methods can be used concurrently; for example, integration of solar energy with fossil fuel power, electric and biomass in form of wood or thermophilic process; or integration of electric and thermophilic energy. Unfortunately, these alternative energy systems can be costly—thermophilic energy is cheap and result into conversion of waste into compost which can eventually be used as manure to improve crops yields.

Bulk fish production continues to suffer losses from poor preservation and more specifically inadequate drying in many rural communities. Mechanized dehydration is preferred over the traditional open-air sun drying but is energy intensive and costly. Minimizing energy losses and enhancing process efficiency remain key priorities for dryer design. In this study, the energy saving potential of integrating compostable insulations in the dryer walls was evaluated under the assumption that supplementing process heat with energy from thermophilic decomposition of the biodegradable materials could enhance efficiency. The influence of thermophilic energy on drying processes remains undocumented.

1.2 Objective

The main objective of this study was to evaluate the performance of a hybrid electro-thermophilic silver cyprinid dryer.

This was achieved by doing the following:

Specific Objectives

1. Characterization of batch of drying silver cyprinid integrated thermophilic energy vis-a-viz the pure electric system;
2. Establishment of appropriate models for the drying kinetics; and

3. Evaluation of the energy saving potential of the integrated thermophilic energy vis-a-viz the pure electric system.

1.3 Justification

Most studies on hybrid electric dryers focus on supplementing it with fossil fuel for instance biomass (wood),solar energy, among others; this study will supplement the pure electric energy by utilizing the energy produced by metabolic processes of thermopiles derived from agricultural wastes. The study therefore provides a new area of research with respect to complementing an electric dryer with a renewable source of energy in the form of thermophilic energy.

It also contributes to eradication of poverty; zero hunger; good health and wellbeing; affordable and clean energy; and responsible consumption and production, which are among the 17 agendas for 2030 under Sustainable Development Goals (SDG). Efficient drying process means abundance of food, which is clean and with a lot of nutrients, this improves the livelihood of people and assure food security. The high cost of energy resources demands for use of modern energy efficient technologies that are economically sustainable and technically less complex—these must satisfy the resolve to quality dried products and in the process save the energy resources (Pokholchenko and Smirnova, 2019).

1.4 Scope

The study only applies to one fish species, Silver Cyprinid (*Dagaa/omena*) from Lake Victoria. The analysis will mostly concentrate on the characterization of the drying kinetics , mathematical modeling of drying characteristics and evaluation of energy saving potential of the hybrid dryer.

The study was conducted in Kitale, a town in Western Kenya and the focus of the study was on the science of effectiveness of the drying system using both pure electric and hybrid electro-thermophilic dryers. It should be noted technology transfer stage, that include scalability and energy saving, will be implemented at a later study using local parameters including prevailing climate of L. Victoria and Kisumu region where majority of the Silver Cyprinid is sourced in Kenya.

1.5 Structure of the study

This study is organized into five sections—the first section includes the introduction which constitutes the background for the study, problem statement, and the research objectives as well as the scope of the study. The second section include the literature review and the state of knowledge on the topic that is combined with theoretical approach. Methodological approach to the study; and results, analysis and discussions are presented in third and fourth sections respectively. Conclusions and recommended themes for future studies on the effective drying of Silver Cyprinid, are presented in the fifth section (the last section).

CHAPTER TWO

2.0 Literature Review

2.1 Drying mechanism

Meat, eggs and fish are considered as nutritious foods, but fish is more nourishing than the two (Patterson et al., 2018). In comparison to fresh fish, dry fish maintains a higher amount of nutrients per unit weight (Id et al., 2018) . The composition of a fresh fish by mass, according to Abraha & Admassu (2018), is as follows: water (70-84 %); protein (15-24 %); fat (0.1-22%); 1-2% minerals; 0.5% calcium; 0.25% phosphorus; and the rest constitute vitamins A, B, C and D. In order to achieve a good-looking, fresh and high shelf life characteristic in a fish product, fish must be subjected to either high or low temperature treatments comprising: chilling, freezing, canning, smoking, drying, salting, frying and fermenting, sun-drying, grilling and frying, as well as the mixture of number of these methods (Abraha & Admassu, 2018).

The actions of enzymes, yeasts, bacteria, and molds, can cause spoilage of food, this is curtailed through reduction of moisture content during drying process (Belessiotis & Delyannis, 2011).The drying process, therefore, involves the removal of water from the substance being dried—this occurs when the heat is supplied to the moist material leading to vaporization of the water content making the liquid to move to the boundary of the product being dried after which it is swift away by carrier medium like the moving air (Nwakuba et al,2016).

Water is the largest constituent and it exists in three states in food: free water, adsorbed water and water of hydration. The free water acts as the dispersing agent for colloids and solvents in salts; adsorbed water is highly embedded in cell walls of fish and as a result it is held firmly to proteins. Water of hydration on the other hand represent water that is chemically bound, for instance salts (such as $Na_2SO_4 \cdot$ 10HO.2) and lactose monohydrate (Nielsen, 2010). The author also stated that nature of how water exists in a food product dictates its removal process. Among the three status of existence of water in food substances, free water is the most susceptible to easy removal.

Two basic moisture transfer mechanisms are also involved in drying: movement of internal moisture within the tissues to the surface, and transfer of this moisture, in water vapor form, to the environment. This is an endothermic process and as a result noticeable cooling is observed in the drying chamber, for this reason ,when several samples are placed in an oven or drying chamber a temperature drop is noticed (Nielsen, 2010). The evaporation process is described as a dehydration process of food product—a thermal process of freeing food products of moisture held in their tissues by use of heat (Chang, 1982). Fish drying process like any other food drying process involves a series of two processes that are facilitated by two major drying parameters: temperatures and the convective nature of drying, for forced convective it is provided by the electric fans. Due to changing temperature gradient as the result of dryer heat, the moisture in the fish migrate to the exterior or surface of the fish tissue where its evaporation happens as a result of forced convective impact of the circulating air by the fans (Nielsen, 2010).

There are basically two drying rate periods—the constant and falling rate period. According to Hubackova et al., (2014), the drying process of a product is preceded by the constant rate where most of the drying occurs , followed by the falling rate period, this process then comes to an end at a point where the equilibrium is established. They go ahead to state that the constant rate period occurs under surface diffusion mechanism and towards the end of this rate period the capillary forces move the moisture to the surface—this continues until critical moisture content is achieved, and this particular stage marks the beginning of the falling rate which is characterized by the liquid diffusion mechanism. The second falling rate period involves moisture movement due to moisture concentration difference and it is characterized by vapor diffusion mechanism (Hubackova et al., 2014). In his experimental study on the effects of pre-treatment and drying temperature on drying rate and quality of African Catfish using different pre-treatments (salting, sugaring, blanching, and control) at 40 ^{0}C to 55 ^{0}C; Omodara (2012) concluded that the drying happened in the falling rate period, suggesting internal mass transfer as the prime mass transfer mechanism for the experiment.

2.2 Factors affecting drying process

Belessiotis & Delyannis (2011), defined drying as a process of achieving standard specification of moisture content through removal of excess moisture from either natural or industrial products. Kumar et al (2017) also described the drying as an attainment of the equilibrium moisture content (EMC) when evaporated water within the substance being dried is removed through its porous media then through its thin layer. According to Reyer et al., (2020)the conditions of the drying air such as temperature, relative humidity and velocity highly affect the rate of drying—the impact of these parameters on drying trend as well as the quality of the product being dried is dependent on the nature of the product being dried. Accordingly, Osodo and Nyaanga (2018); and Kumar et al (2017) mentioned air temperature, air velocity, porosity of product, variety, maturity, layer thickness and moisture content of product as the major factors affecting drying rate.

For water to vaporize from the outer surface of the product being dried , three heat transmission mechanisms according to Maisnam et al (2016) (convection, radiation, and conduction) are applied—the evaporated vapor is then removed by the influence of air flowrate over the surface. Maisnam et al (2016) continued to assert that conductive and convective techniques are the most preferred techniques that the conventional drying methods rely on; however, these two techniques have a disadvantage of exposing the dried product to termination and eventually producing a poor-quality product.

One of the indicators of a drying is the moisture removal rate (MRR) which quantifies the amount of water released in the substance being dried. Drying process is affected by so many factors for instance air velocity , intensity of temperatures, air velocity, etc.; while investigating the effect of air velocity, layer thickness, number of trays and temperature on moisture removal rate (MRR), Osodo and Nyaanga (2018) concluded that the MRR increased with increase in both drying air velocity and temperature at constant layer thickness— at constant air velocity the MRR decreased with increase in layer thickness. There are several methods of setting or controlling the volumetric air flowrates in a dryer, according to Mercer (2014), which can be implemented by regulating the speed of the fans; varying the sizes of the louvres or altering volume control disks on certain forms of fan assemblies.

Both higher drying temperatures and higher air velocities decrease drying time: at higher drying temperatures the substance's internal thermal gradient increases and this leads to decreased drying time— higher air velocity decrease the vapor pressure leading to reduced resistance experienced by the exiting substance's moisture to the outer surface (Nwakuba N.R., et al, 2016b).

The diffusivity of moisture to the external surface of the substance being dried is a transport characteristic related to rehydration or drying of solids (Jain & Panthare, 2006). The amount of moisture removed in a sample is dictated by drying time (which is a function of surface area per unit weight of sample, overall moisture content and the type of food sample) and the degree of drying temperature. These two functions according to Nielsen (2010) may lead to decomposition of the product if they are extreme. The decomposition relates to nutritional constituents of food like carbohydrates, protein, fats and volatile components for instance acetic acids, esters and aldehydes, which have certain degree of heat threshold, beyond which they are denatured.

Circulation of air over the surface being dried is paramount. Lack of air movement over the boundary of the sample being dried leads to a stagnant boundary layer, saturated air, which can be removed by passing unsaturated air that picks moisture at the surface (Mercer, 2014). Continuous supply of fresh unsaturated air leads to the complete removal of the moisture at the surface, during drying process, since the removal of the saturated air at the surface renews the moisture gradient hence the internal moisture is transferred to the surface and eventually removed. The flowing air helps in dislodging away the stagnant boundary layer, increase in the unsaturated air flowrate leads to faster sweeping away of the moisture at the surface, hence faster drying (Mercer, 2014). An increase in air velocity leads to an increase in moisture removal rate; greater air flowrate enables sweeping away of much moisture (Osodo & Nyaanga, 2018).

According to Varun et al. (2012), for longer period storage, drying process facilitates the removal of moisture as well as prevention of the reproduction of micro-organisms in the product being dried. However, temperatures have to be moderate, high temperatures and prolonged drying periods lead loss of food quality in product being dried; therefore, application of relatively lower heat provides minimal thermal effect necessary for heat-sensitive materials drying (César et al., 2015).

The quality of the dried sample product is considerably influenced by three factors: the quality of raw materials, the processing variables of the process, and the drying techniques applied. The quantity of the total moisture, the nature of the food being dried and the surface area per unit weight of the substance being dried, determine the drying time of the sample (Nielsen, 2010).

Sample's size , its thickness, determines how fast it is dried; in a drying system where there are different tray settings, the size of the sample increases with an increase in the number of loaded trays. Osodo and Nyaanga (2018) concluded that the increasing the number of trays doesn't have much effect on the moisture removal rate since heated air doesn't require any additional capacity to remove the saturated air—they also found out that at constant air velocity the rate of moisture removal decreases with increasing layer thickness of a sample.

2.3 Fish drying techniques

There are majorly two broad categories of the drying processes: artificial and natural drying techniques (Maisnam et al., 2016). The natural drying methods are those whose sources of energy are derived from nature and are majorly composed of the solar drying technique that is further classified into direct and indirect drying techniques based on the mode at which sample being dried is exposed to drying heat.

Consequently, dryers are classified based on the period of invention (traditional or ancient, and modern dryers). The modern dryers are the current generational dryers and the traditional ones are those which were applied in the ancient period, some are still in application , but the advancement in innovation about their usage is low or minimal. In traditional methods of preserving fish, the action of the sun and wind is used to effect evaporative drying. In recent times, smoking kilns and artificial dryers are used to obtain product of high quality (Omodara, 2012). Subsequently, the artificial drying techniques are those whose performance are driven by the effect of mechanical and electrical mechanisms. This drying consists of convective drying , drying through radiation, free drying, and osmotic drying. In the convective drying technique, the water removal process is achieved by exposing the drying equipment to the heat and a good example is the use of hot air tunnel dryer; the drying by radiation process , for instance microwave drying (involves exposing the sample being dried to heat through radiation) as this ensures proper preservation of the essential and heat sensitive components of the food being dried (Maisnam et al., 2016). Osmotic drying involves osmosis process that exposes the substance in a hypertonic solution effecting osmotic dehydration; and the freeze drying on the other hand is the exposure of the product to freezing substance.

Different dyers are used to dry fish, based on the type of fish species, the dryers are expected to offer a number of temperature ranges and it is imperative to pay attention to the tolerable drying temperature to achieve a well dried fish (Yuwana & Sidebang, 2017). According to Omodara (2012), the type of drying technique employed is reliant on fish characteristics for instance size, quantity and the nature of fish being dried, others are the end users' taste preference, economic considerations and the quality of fish dried.

Since the heat is projected from a designated location in the dryer, the propagation to all parts of the dryer must be executed through circulation of the heated air. The heated air inside the drying chamber has to be circulated effectively for fast and even drying of the product being dried, using natural convection or forced convection. Forced convective methods like the use of electric fan are the most efficient, and according to Abdulmajid (2015), their ability to maintain continuous circulation of air make them the most appropriate for drying of products with high moisture content. Citing the work of Buchinger &Weiss (2002), Abdulmajid (2015) state that active dryers have more overall drying potential of 20-30% compared to passive dryers (10-15%).The use of electric energy to power fans for air circulation in most hybrid dryers, makes their application a big challenge in areas without electricity grid mostly developing countries according to Yuwana & Sidebang (2017); besides, adding an additional energy consumption cost. The high cost and scarce supply of electricity has made it hard for the fishermen, majority of whom are poor, to use electric powered fish preservation technologies (Odote et al., 2015).

The fact that some dryers are equipped with heat storage, solar energy, to lengthen their drying ability does not deter the effect of extreme weather like heavy rains (Yuwana & Sidebang, 2017).

Among the drying techniques: vacuum, forced draft and convection ovens—forced draft ovens offer the least temperature variation within the oven since the air movement is facilitated evenly within the oven; however, due to lack of fan, the convection oven always presents the highest temperature variation (Nielsen,2010).

A number of studies have been carried out on the potential of firewood to provide effective drying heat source. However, the use of firewood for smoke drying has serious environmental effect as it encourages deforestation and the smoke from the burning firewood presents a fatal health hazard to those involved. In their study, Odote et al (2015) recommended the use of safe technologies which are friendly to the environment in storage and preservation of fish products.

The study on the effects of smoke-drying temperatures (50, 60 and 70°C) and duration of drying (5, 10 and 15 h respectively) on the quality of Nile tilapia (Oreochromis niloticus) by Idah et al (2013) explained drying time and temperature both affect the drying and quality of fish, but at varying degrees—the results concluded that the best quality parameters for effectively dried product were at 60°C for 15 h and 70°C for 10 h.

Belessiotis & Delyannis (2011) described solar radiation as one of the ancient methods of solar energy usage—it has been used for drying of food, cloths, construction materials just to mention but a few. Citing Ajay et al (2009), Babagana et al (2012) defined solar drying as a process that utilizes solar energy to heat air as well as products in order to enable the drying process of agricultural products. In developing countries where majority of the population don't have access to artificial dryers, open sun drying presents easiest, user friendly and less expensive means of food preservation (Abdulmajid, 2015).

Solar dryer is a modern food drying technique by use of sun energy. Solar drying techniques are categorized as direct (open-air sun drying), indirect (convective solar drying), (Belessiotis & Delyannis, 2011; Gatea, 2011); Gatea (2011) further added a third category, mixed-modes method. The methods differ in how solar energy is passed to the substance to be dried. The direct dryer has a transparent cover through which the solar energy passes to the substance to be dried, the indirect dryer on the other hand has air heater (solar collector) that collects solar energy and passes it to the drying cabinet. The mixed mode enables both direct and indirect drying processes (Gatea, 2011). Detailed descriptions and the operation of the three solar drying techniques, that is the indirect, direct, and mixed mode drying techniques, together with identification of the active and passive mode of the three drying techniques, are outlined by Mustayen et al (2014). They also go further to explain the effect of the surrounding environment on solar energy and subsequently on solar drying process.

Among the three solar dryers, indirect drying is the most used drying method—it involves heating process by convection between hot air and products surface. The heated air is circulated all over the product, releasing the moisture to the atmosphere in the process of heating (Belessiotis & Delyannis, 2011).

2.4 Thermal mass and thermophilic process

In their study of compost heat recovery systems (CHRSs), Smith and Aber (2017) pointed out that the process major output is the recovery and usage of heat produced and not the biogas—the process is purely aerobic and the methane gas produced is less utilized.

According to Kikani et al (2010), there is less exploration of the thermophilic organisms which they attributed to difficulty in maintenance of pure culture as well as isolation of the culture, but they have appropriate characteristics for biotechnological and commercial usage, as stated by Mehta et al (2016) in their study. They also assert that it is important to numerous adaptive mechanism thermophilic bacteria and actinomycetes are capable of rapid growth as well as producing biotechnologically valuable compounds, such as thermostable enzymes at optimally high temperatures (Kikani et al., 2010). There is a great demand for thermostable enzymes as a result of ever-increasing industrial growth attributed to effective increase in utilization of biocatalysts—this is fulfilled through production of functional enzymes into mesophilic host by molecular cloning and overexpression of genes from thermophilic. However, according to Mehta et al (2016), there is less exploration of the enzymes responsible for breakdown of the thermophilic biomass. As a source of thermostable enzymes, the study of thermophilic microorganisms has become special area of scientific interest since there is a considerable demand for a new generation of stable enzymes that are able to withstand severe conditions in industrial processes by replacing or supplementing with traditional chemical processes (Mehta et al., 2016).

Compared to other similar mesophilic species, thermophilic organisms have higher metabolic rates; and are physically and chemically more stable enzymes; and have lower growth but higher end product yields—this is owed to their distinctive nature to prosper at relatively higher temperatures as well as their unique biotechnological potential (Kikani et al, 2010). Thermophiles are found in a variety of environments: the soil, mud or water from regions of widely differing climate, compost, sewage, and in deep ocean floor deposits as well as in hydrocarbon-containing rocks (Eze, 2011).

Cultivation of thermophiles at higher temperatures allow reduction of possibility of contamination, easy mixing, high mass transfer, and provide sufficient viscosity which ensures sufficient degree of substrate solubility (Kikani, 2010; and Turner et al., 2007).

Citing the Brook (1986), Kikani et al (2010) suggested thermophilic bacteria and actinomycetes as the only organisms capable of growing and producing such compounds (such as enzymes, antibiotics, hormones at industrial scale) at optimally higher temperatures. They further went ahead to classify thermophiles on the basis of their tolerance to different ranges of temperature, as: facultative thermophiles (50°C-65°C); obligative thermophiles (65°C-70°C); extremely thermophilic organism that can grow the range of 40°C-70°C; and hyperthermophiles (predominantly archae) can grow at temperatures over 90°C (Brock, 1986). In their study on the survival mechanisms of thermophiles at high temperatures, Guan et al. (2013) defined microorganisms based on their optimal growth temperature (OGT), stating that thermophiles are those with OGT in the range of 60 and 80°C, and hyperthermophiles as those at OGT above 80°C—these microorganisms exist in three domain of life as archaea, bacteria, and eukarya.

The chemical and enzymatic reactions in the cell depend on the temperature of the environment in which the thermophiles are subjected to: at higher temperatures, above a certain point, the cellular components are denatured and at temperatures below optimum, they cell grow faster due to rapid reaction (Eze, 2011).

The temperatures are low at the beginning of the pile formation and within a period of few days the temperatures sharply rise up to thermophilic temperatures, at this stage there is a consumption of digestible materials by the microbes because of increased oxygen demand and hence high production—this heat has to be harvested otherwise there is a risk of subjecting microbes to inhibitive temperatures they cannot survive and eventually start dying off at temperatures above 70ºC. As the decomposition process precedes, the cumulative metabolic rate begins to decline a s a result of reducing microbial population because of depreciating amount of less digestible compounds, this leads to decline of the pile temperature as the process progresses. Since heat extraction is the major objective of the CHRs process, then the two main considerations for sustaining the heat production are : (1) upholding pile temperatures in the range of 54-66ºC, and (2) maintaining the point plateau on the curve. Besides these, the microbial living conditions should be optimal for responsive flourish and reproduction of the microbes leading to production of maximum heat (Smith & Aber, 2017).

In conclusion, the drying process of fish requires consideration of various physical and thermal properties in the design phase of a dryer, these parameters according to Abdulmajid (2015) are:

diffusivity of moisture; dependence on temperature and input air velocities; activation energy; and specific energy usage. The author went further to suggest that the air temperature, relative humidity, amount of sample, moisture content, degree of solar insolation, speed of airflow and the thickness of the sample, as the properties dictating the efficiency of the dryer.

2.5 Fabrication and scale of a dryer

The fabrication and scaling of a dryer is a phenomenon aspect of the drying process. The specific measurements, structural designs and the type of materials used for the construction of different components of the dryer as well as the geometric evaluation of the whole drying system, are some of the critical features considered in the design of a dryer.

According to Pokholchenko and Smirnova (2019), three aspects have to be put into consideration in the process of designing contemporary technologies and approaches of raw produce material processing: safety of produce for consumption, competitive energy cost, and relatively minimal cost of labor.

In their design and fabrication of a convective fish dryer under no load condition, Komolafe et al (2011) presented a detailed design, fabrication and preliminary experimental results. Using fabrication materials such as galvanized metal sheets, angle iron stainless steel, etc. they designed a dryer that consisted of five main components: the base frame, the drying chamber, the drying cage, the fan housing and the electric heating element. The heating element provided the heat and a fan that enabled even propagation of the heat within the drying chamber, as well as fasten the drying process. They concluded that the convective drying system capable of supplying as high as 110°C drying chamber temperature was an alternative for local drying techniques more especially in harsh weather conditions like heavy rains.

Similar studies were conducted by Hamdani et al. (2018) in which they fabricated and tested a hybrid solar-biomass dryer for fish drying using medium size Queenfish as their sample, in order to investigate the dryer's performance and carry out financial analysis of dried fish production business. The equipment used included biomass fueled air heaters, solar energy drying chamber, a fan, and a chimney. The sample was subjected to three different drying techniques (treatments): direct solar drying where solar is the sole source of energy used; biomass drying process where hot air was applied to facilitate drying process; and the hybrid process that started with solar drying process and followed by biomass energy drying process. They came to a conclusion that it took only 15 hours to dry fish using hybrid solar-biomass dryer because in an event where there was no sunlight the biomass energy was used to operate the system.

In their study, Babagana et al (2012) designed and constructed a forced and natural convection solar dryer for vegetable drying, with heat storage. The study was used to dry tomato, onion, pepper, okra and spinach—the forced convection mode system gave better drying rates compared to the natural mode system. The equipment consisted of a solar absorber of the collector constructed using 0.55 mm thick corrugated aluminum plate (painted black) with a bottom insulated with plywood, which was attached on a box built of the same area—a single layer glass sheet was placed at the top of the collector to form a greenhouse effect. The drying chamber, which contained drying trays, had structural frame made from well-seasoned gmelina wood, which was covered with plywood sheet. The drying chamber had a chimney attached to it as an outlet for the exhaust heat.

2.6 Thin Layer drying, drying kinetics and mathematical modeling

By definition, thin layer drying is the drying of substance or sliced pieces of that substance as single layer. The thin layer drying equations are mathematical drying models that provide practical and adequately appreciable analysis used with the knowledge of the drying-rate curves of the experiments (Hubackova et al., 2014). The application of thin layer drying in studies enables comprehensive understanding of the distinctive drying characteristics of any particular food material being experimented on (Aregbesola et al., 2015).

Drying is process associated with evaporation of water into vapor phase through the application of thermal energy on the substance being dried; however, as a result of complications and deficiencies in the descriptions of the mathematical models; drying has been among the least comprehended processes especially at the microscopic level (Hubackova et al., 2014) .

Drying process present a complex array of parameters that envisage the application of multifaceted drying kinetics and mathematical models that can be used to precisely predict the drying outcomes through proper interaction of various drying parameters and dryers' characteristics. Therefore, investigation and comprehension of the drying kinetics play critical role in determination of drying technique employed and the control process of the drying process being applied (Maisnam et al., 2016). In drying, it is important to optimize the findings of the experimental investigations of the dryer , this calls for assessment of the impact of fish mass and varied air velocities by conducting a simulation-based assessment (Izdiharrudin et al., 2019). Citing Khazae and Daneshmandi (2007), Maisnam (2016) classified drying models into three categories: theoretical, semi-theoretical and empirical models.

2.7 Dryer Performance and Specific Energy Consumption (SEC)

The dryer's performance, which is associated with efficiency of a drying system, is the most important characteristic determining the applicability of any drying system. It is related to the energy consumption which is defined as how much water has been removed from the substance being dried. The energy consumption of any drying system , according to Nwakuba et al (2016) , is dependent on a number of parameters such as thickness and geometry of substance being dried; initial and final moisture content of the sample; sample's specific heat; design of the dryer; and the operating conditions of the dryer like the temperature, air velocity, power density, pressure , sample's energy requirement, drying time, among other parameters. The thermal efficiency and the specific energy consumption (SEC) are the two main indicators for the assessing the drying system's energy performance (Nwakuba et al, 2016a). Performance of a dryer is defined as a function of two drying parameters , amount of water removed and amount of energy used to energy consumed in the process, which constitute the dryer's specific energy consumption (SEC). By definition, specific energy consumption (SEC) is the amount of energy needed to remove one kilogram of water from a product being dried (Nwakuba et al, 2016a).

At initial stages of drying process, constant rate period, the specific energy consumption (SEC) values are higher due to high amount of moisture being removed, as the process proceeds the SEC values decrease because of the decreasing amount of moisture being removed (Nwakuba N.R., et al, 2016b).

CHAPTER THREE

3.0 Materials and Methods

3.1 Description of the hybrid electro-thermophilic dryer system

3.1.1 Equipment

The dryer is designed for a capacity of ten trays (as shown in Figure 1 below) each having a capacity of 800g of Silver Cyprinid fish per batch. The dryer is comprised of thermophile carriage at the top; a drying chamber partitioned into two to accommodate 5 trays on each partition of the chamber; fan housing; 1kW electric heater; ten wooden trays with stainless steel wooden mesh; and a heat sink(heat collector) with a depth of 500mm.

Figure 1. Open Fish Dryer

Figure 2. Insulated fish dryer

3.1.2 Drying chamber

The drying process occurred between the heat collector and the heat sink; the roof of the chamber is the thermophile's trough, and the bottom is the heat sink. It consists of ten removal wooden panels (trays) that overlap each other, and a set of electric fans ran by electric power which provide forced convective process of heat propagation within the chamber and the heat sink. The walls of the chamber are made of the metallic plate with dimensions of 1150mm x 600mm x 1500mm. A door is hinged on either side of the drying chamber to permit access inside the chamber for loading and offloading of the sample; access to heat sink and the electric fans; and permit installation of instruments. Each of the two doors for the two partitions of the chamber had a smaller door (of about 250mm by 200m) hinged on ,used to monitor the progress of the drying.

The drying chamber is divided into two and the fans are positioned in reversed orientations to those on the adjacent sub-chamber and each side has a set of four fans of four blades. These fans are mounted below the thermophile carriage to sufficiently force heated air into the drying chamber across the drying trays as well as expel the moist air from chamber into the heat sink as a result avoid stagnation of heat and moisture.

3.1.3 Drying trays

The drying chamber contain drying trays whose frames are constructed using wooden material and the upper part (the sample holding section) is made of fine wire mesh of approximately 5mm diameter on which the fish are spread in order to be dried. The mesh is designed in such a manner that allows the trays to withstand the weight of the sample to be dried and allow free movement of the heated air. It has the dimension of 500mm (length), 500mm (width) and 50m m (thickness) this equate to a total tray area of 0.25m^2. The trays are arranged equidistantly with a spacing of about 50mm

3.1.4 Heat sink

Underneath the drying chamber is a heat sink that facilitates the cooling process of the heat from the drying process as well as stabilize the humidity inside the dryer.

3.1.5 Thermal mass (biomass)

The biomass is contained in the upper component of the dryer that is opened at the top and is separated from the drying chamber by a single partition of a metallic sheet.

Thermophile Composition: 1 bag (15kg) shredded maize stover, ¾ bag cow manure, ¼ bag of shredded grass manure (av. 1 bag of cow manure 52kg), and 50kg water. In the experiment two thermocouples were mounted at the bottom and at the top. The pile was aerated through the white duct shown, with air supplied by aquarium pump (Sera Precision Air 275R Plus) with supply rated at 275 l/hour. This provide a conducive environment for the thermophilic bacteria to feed, reproduce and in the process release heat, which is utilized as thermal heat. To be ready for use as source of drying energy, the various constituents of the thermophile are sourced and mixed in the defined proportion. The thermophile is given a day to allow the microbes to activate and the system to start generating heat.

Figure 3. Empty thermophile carriage

Figure 4. Preparation of the thermophile

3.2 The preparation of Silver Cyprinid sample

The fish species used for this study was Silver Cyprinid locally known as *omena* or d*agaa*—it measured about 60 (±5) mm length, and 15 (±2) mm width. It was chosen because of its readily availability as the most caught species in Kenya , affordability, and the fact that less study has been done on its efficient drying and reduction of post-harvest losses. The fish was sourced from the shores of L. Victoria (Kisumu), Kenya which is 200Km from Kitale. The Silver Cyprinid sample was thoroughly washed with clean water and kept in iced boxes and transported over a journey of 3 hours to Kitale. Upon arrival in Kitale the fish was thoroughly washed again and sorted out for any existing foreign objectives like stones, sticks and debris; outliers like relatively large or small fish were removed too. The sample to be dried were weighed in preparation for experimentation and the remaining portion was kept in iced boxes for preceding experiments.

3.2.1 The Silver Cyprinid drying process

The sample were weighed and spread on the drying trays with care being taken that no single fish lied on top another sample, to effect thin layer drying mechanism, with each tray handling a capacity of 800g of fish; this was the established capacity for even spreading and non-congestion and overlapping of the samples. This means that one tray experiment contained 800g; and the 5-tray and 10-tray experiments contained 4,000g and 8,000g capacity respectively.

The loaded trays were then placed on the preheated dryer based on the specific design of each experiment. The arrangement was in such a way that each tray was explicitly exposed to the predetermined heat and air velocity conditions. The progress of the drying process was monitored through periodic weighing of each tray at intervals of 2 hours using cell powered digital electronic balance. The experiment continued until the change of the sample mass was less than 1% or no mass change was noticed, at this point the experiment was stopped and the final weights and equilibrium relative humidity determined.

Figure 5. Dried fish sample **Figure 6. Loading the wet sample into the dryer**

3.2.2 Bone Dry

After the experiment, 50g of each experimental unit was collected and kept in sealed air-tied containers, these samples were then transferred to Mechanical, Industrial and Textile (MIT) Engineering Laboratory at Moi University School of Engineering. Using AOAC (2005) standards for the determination of final moisture content using hot air oven method, pre-weighted pre-dishes were dried in a hot oven under temperature of 110 ºC for time of an hour, they were then hurriedly enclosed and cooled in a desiccator, after which their final weights were determined (W). Samples of fish (in the range of 3 $\pm$ 0.5g of each) were placed on the petri-dishes and covered, and hurriedly weighed to avoid possible loss of moisture (W).The loaded petri-dishes were then uncovered and placed in the oven dryer at 105ºC for 24 hours. The dried samples were then removed and cooled in desiccators to room temperature after which they were weighed using an electronic balance. Finally, moisture content (MC), moisture ratio (MR) and drying rate (DR) were calculated using the formulae provided in equations [1], [2], and [3] respectively.

A. Moisture content, % (d. b.)

$$MC\% = \frac{w_2 - w_3}{w_2 - w_1} \times 100 \qquad [1]$$

Where:

W_1=weight of an empty petri-dish

W_2=weight of undried sample and the petri-dish

W_3= weight of dried sample and the petri-dish

B. The moisture ratio (MR) is determined using the following equation:

$$Moisture\ Content(\%) = \frac{Initial\ weight - oven\ dried\ weight}{Initial\ weight} \times 100 \qquad [2]$$

C. Drying rate (DR), as a function of change in moisture content against time interval is calculated as follows.

$$DR = \frac{\partial M}{\partial t} = \frac{MC_1 - MC_2}{\Delta t} \qquad [3]$$

Where,

$MC_1\ is\ the\ moisture\ content\ (\%\ dry\ basis) at\ time\ t_1$

$MC_2\ is\ the\ moisture\ content\ (\%\ dry\ basis) at\ time\ t_2$

$\Delta t\ is\ the\ time\ subesequent\ time\ difference$

3.3 Design of the experiment

The hybrid electro-thermophilic dryer is an enclosed system where the air inside circulates between the warm temperature region of the dryer and the cooler area of the heat sink. The system was energized by the heat produced by an 1kW electric heater and thermophilic energy provided by the thermophile. The heat was propagated inside the drying chamber by a set of electric fans that were adjusted manually to provide both low (1.4 m/s) and high (2.8 m/s) velocities depending on the requirements of each specific experimental test. The experiments were conducted also on the basis of the number of trays with each tray having a capacity of 800g of fresh fish. The 5-tray experiment and 10-tray experiments had 4,000g and 8,000g each respectively—the temperature settings were 40°C and 60°C; the electro-thermophilic drying was only subjected to high air velocities and high temperatures for only 5-tray and 10-tray experiments. The experimental setup is as described in the table below.

Table 1. Experimental set-up

S/N	**Experiment**	**Parameters**		
		Air velocity [m/s]	**Temperature setting [ºC]**	
			Low [40ºC]	High [60ºC]
A	**Pure Electric Drying**			
1	One-Tray	1.4 m/s	✓	✓
2	One-Tray	2.8 m/s	✓	✓
3	Five-Tray	2.8 m/s	✓	✓
4	Ten-Tray	2.8 m/s	✓	✓
B	**Electro-thermophilic Drying**			
1	Five-Tray	2.8 m/s	-	✓
2	Ten-Tray	2.8 m/s	-	✓

3.3.1 Phases of the experiment

3.3.1.1 Pure electric drying

For the pure electric drying tests, eight experiments were conducted: four for one-tray, 2 for five-tray, and two for ten-tray experiments. The one-tray experiments were at high temperature and high velocity (HTHV), high temperature low velocity (HTLV), low temperature high velocity (LTHV)and low temperature low velocity (LTLV). Five-tray experiments had only two tests: high temperature high velocity, and high temperature low velocity. Finally, the ten-tray experiments, had two tests too: high temperature high velocity (HTHV), and high temperature low velocity (HTLV).

3.3.1.2 Hybrid electro-thermophilic drying

There were only two tests for the hybrid electro-thermophilic drying (both five-tray and ten-tray experiments) that were each subjected to high temperature and high velocity (HTHV).

3.3.2 Instrumentation

Temperature, relative humidity, air velocity, weights of the fish, voltage, and time were measured and recorded. Temperature measurement inside the dryer was carried out using two sets of thermometers: portable digital thermometer (Testo comfort basic 5.0) placed on one of the trays; and thermocouples connected to a data logger recording at $\pm 1\%$ °C accuracy —temperatures were measured at three positions, at the top and bottom trays and at the heat sink at an interval of 1 minute. The weights of the representative samples of Silver Cyprinid were taken, quickly to avoid any interference with the drying process, using an electronic balance at the beginning and at hourly intervals until the weight was constant—at this point the sample was assumed to have attained equilibrium . Relative humidity was measured simultaneously with the temperature by Testo Comfort basic 5.0 at intervals of 1 minute. The electric power consumption measurement was recorded using a digital instrument (EasyLog USB Voltage Data Logger: with a measurement range of 0 to 3.0V d.c and precision of $\pm 1\%$ that measured voltage at an interval of one minute. Digital anemometer (Hyelec MS6252) with a measurement range of 0.8 to 30.0 m/s and precision of $\pm 2\%$ was used to measure the air velocity produced by the fans inside the dryer.

3.4 Determining the Influence of temperature, Air velocity and the number of trays on drying rates

3.4.1 Influence of Temperature

To determine influence of temperature on the Silver Cyprinid drying process, the well-prepared Silver Cyprinid were tested at temperature settings of 40°C and 60°C. Each temperature setting was subjected to different air velocities 2.8 m/s and 1.4 m/s—heat was provided by a 1kW electric heater whose temperature was controlled using proportional integrated device (PID) that maintained the temperatures at stated thresholds.

Keeping each experiment at respective constant air velocity setting, the sample was exposed to different temperatures at different tray settings. The effect of air temperatures at constant air velocity was then deduced at each sample experimental tray setting—the variation was then attributed to the amount of temperature provided.

3.4.2 Influence of Air Velocity

To determine effect of airflow rate on the Silver Cyprinid drying process, the well-prepared Silver Cyprinid were tested at air velocities of 2.8 m/s and 1.4 m/s at constant temperature. Each air flowrate was subjected to 40°C and 60°C at various tray settings—heat was provided by a 1kW electric heater whose temperature was controlled using proportional integrated device (PID) that maintained the temperatures at predetermined setting.

Maintaining the experiment at constant temperature, the sample is exposed to different air velocities at different tray settings. The effect of air velocity at constant temperature is then deduced for each sample tray setting—the variation was then attributed to the difference in the intensity of air velocities provided.

3.4.3 Influence of the number of trays

The influence of the number of trays at defined amount of temperatures and air velocities was defined by comparing the moisture removal rate (kg moisture.kg^{-1} wet fish hr^{-1})—this involved utilization of the analysis applied by Osodo and Nyaanga (2018) in their study of the effect of number of trays on the moisture removal rates (MRRs). They computed the moisture removal rate as a ratio of amount of moisture removed at the end of each experiment and the total number of hours for each particular experiment as shown in Table 3 in Chapter Four on Results, Analysis and Discussions.

3.5 Data Analysis

Drying curves were determined gravimetrically; Graph Expert™ was used to derived different parameters of the selected mathematical models like coefficients (like k, a, and n), the coefficient of determination (R^2) and standard error of estimate (SEE); and SPSS 26 and MS Excel were used for statistical analysis.

3.6 Testing and validating the best thin layer drying model for the experiment

3.6.1 Mathematical Modelling of Drying Curves

The moisture content data at the different drying air temperature and air velocities were converted to moisture ratio. Moisture ratio, MR was obtained for the thin-layer drying, for this case the data from the 1-tray experiments. Subsequently graphs of moisture ratio (MR) against time (t) at different drying temperatures and air velocities considering different tray settings and sources of energy were drawn. Drying data of the Silver Cyprinid at thin-layer drying were fitted to six drying models (e.g. Lewis, Page, Henderson & Babis, Logarithm, Diffusion etc.) to evaluate the most convenient expression for defining the drying rates—the different thin layer drying models are as presented in Table 2 below. The models were selected on account that they catered for the influence of temperature on the drying characteristics of the sample. The thin layer drying models just described were fitted to the drying experimental data to determine the coefficients *k, a,* and *n;* and the R^2 and SEE at various drying air temperatures and velocities. Statistical analysis validation was carried out where coefficient of determination *(R^2)* was used as one of the main selection criteria for the best model to describe both thin and batch-layer drying curves of silver cyprinid sample; and standard error of estimate (SEE). The goodness of fit was determined by use of as higher values of coefficient of determination (R^2) and lower values of standard error of estimate (SEE).

Table 2. Drying mathematic Models

S/N	Model Name	Model/Equations	Source
1	Lewis	$MR = e^{(-kt^n)}$	Liu &Bakker-Arkema (1997)
2	Page	$MR = e^{(-kt)^n}$	Page (1949)
3	Henderson & Pabis	$MR = ae^{-kt}$	Henderson & Pabis (1969)
4	Logarithmic	$MR = ae^{(-kt)} + c$	Akpinar et al (2003)
5	Diffusion	$MR = ae^{(-kt)} + (1 - a)e^{(-kbt)}$	Kassem (1998)
6	Newton	$MR = e^{-kt}$	Ayensu (1997)

3.6.2 Validating the models

The validation of the selected mathematical models was made by comparing the experimental moisture ratios with the predicted moisture ratios. According to Phanphanich and Mani (2009), the Lewis equation assumes free movement of the moisture to the surface of the material with minimal internal resistance—because of its ease of applicability it has been used by several researchers. They further stated that Henderson and Pabis model development was premised on the fact that drying process is controlled by diffusion. Lewis's equation was modified to produce Page's equation

(Phanphanich & Mani, 2009 , and Page, 1949). Page's equation is a modification of the Lewis equation.

3.7 Evaluation of the energy saving potential of the integrated thermophilic energy vis-a-viz the pure electric system.

For the low and high temperatures, a thermostat set 40 and 60^0C respectively. This controlled the consumption of energy in the dryer. When temperatures where below the prescribed temperatures the heater automatically switched. The ON and OFF times were measured. The energy consumed was a calculated as a function of percentage ON time, total drying time for each experiment , and the rating of the heater (1 KW). The specific energy consumption was then derived for the 10 experiments. For the hybrid electro-thermophilic, comparative analysis is done for the 10 tray experiment at both pure and hybrid drying—less specific energy consumption in the hybrid system was attributed to the influence thermophilic energy.

CHAPTER FOUR

4.0 Results, Analysis and Discussion

4.1 Introduction

This section gives an elaborate detail on the results as well as subsequent discussions on the effects of varying temperatures, airflow rates, number of trays, and the mode of heating on the drying rate of Silver Cyprinid for both thin layer and bulk batch layer dryers subjected to pure electric and hybrid electro-thermophilic energy. It also provides mathematical modeling aspect of the experiment as well as the assessment of drying performance.

The data for moisture content for the pure electric drying was used to determine the rate of change in moisture with drying time (dry basis). Rate of change in moisture (dry basis) is the difference in moisture content (g H2O/g DM) between consecutive sampling times divided by the time interval (h). Figure 7, Figure10 and Figure 11 present the drying rate curves (rate versus drying time) for the drying of Silver Cyprinid under pure electric drying technique. The rate of change in moisture content (dM/dt) was significantly affected by drying time; and drying temperature and air velocity ($p \leq 0.001$). For all the experiments drying rates were highest during the first 4 hours of drying, the duration when the moisture content was high—afterwards, the rates declined gradually until desired equilibrium moisture content was reached signaling the end of the experiment. The moisture removal rate (MRR) for each tray setting experiments was used to determine the influence of the number of trays on the drying rate of each experiment at different tray settings, temperature and air velocity.

The mathematical drying models' constants and coefficients were derived from the rate of change in moisture content data, using Graph Expert^{TM}.

In order to deduce the objectives of the study this section is divided into 4 sub-sections: [1] Characterization of drying kinetics of an elementary thin layer dryer using pure electric drying, [2] Characterization of batch of drying silver cyprinid integrated thermophilic energy vis-a-viz the pure electric system; [3] Establishment of appropriate models for the drying ; and [4] Evaluation of the energy saving potential of the integrated thermophilic energy vis-a-viz the pure electric system.

4.1 Characterization of drying kinetics of an elementary thin layer dryer using pure electric drying

Figure 7 below shows the variation of moisture ratio (dry basis) of silver cyprinid for a single-tray (av. weight: 800g) setting using different sets temperatures, high and low temperatures, each exposed to both high and low air velocities. For the high temperature drying, the initial moisture ratio (dry basis) content was 0.854 and 0.799 g water/g dry matter for high and low velocities respectively.

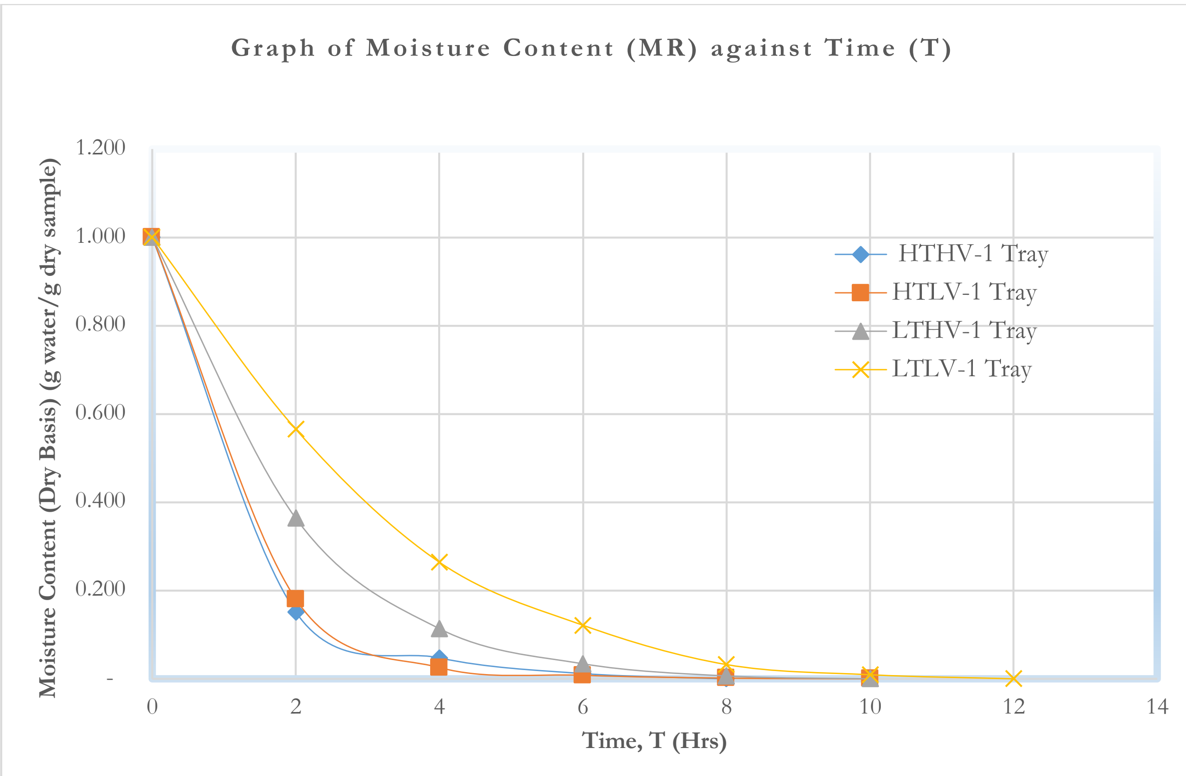

Figure 7. Changes in drying rate of Silver Cyprinid for 1-Tray Experiments

4.1.1 Influence of temperature and air flowrate on drying rate on drying rate

The total drying times to reach the equilibrium moisture content for HTHV and HTLV was 8 and 10 hours respectively. Subsequently, for the low temperature drying, the initial moisture ratio (dry basis) content was 0.790 and 0.833 g water/g dry matter for high and low velocities respectively. The total drying times to reach the equilibrium moisture content for LTHV and LTLV were 10 and 12 hours respectively.

The drying rates for high temperature-high air velocity (HTHV) after 4 hours of drying were 71% higher than the ones dried at low temperature-low velocity (LTLV). After 8 hours, these rates declined to values 68% lower than the low temperature-high velocity (LTHV).

To determine the effect of the air flowrate on the rate of drying, the dryer was fixed at either high or low temperatures and then each was tested at high and low air velocities as shown in Figure 7 above. Keeping the air flowrate constant, at high air velocity for a single tray; the drying rates for low temperature -high air velocity after 4 hrs. of drying were 42% higher than the ones dried at low temperature-low velocity. After 8 hours, these rates increased to values 50% higher than the low temperature-low velocity. This is an indication that the drying rate of Silver Cyprinid increased with an increase in drying airflow rate, this is in line with Fick's law that high concentration gradient between the sample's interface and the drying air is as a result of high air flowrate at the surface of the product being dried. As a result of high diffusion gradient there is a high moisture transfers from the internal tissues of the fish to the surface, increasing the flowrate leads to an increased diffusion gradient. Osodo & Nyaanga (2018) confirmed this in their study on the effect of selected parameters on moisture removal rate, in which an increased air flowrate led to an increase in the drying rate. As the sample is continuously subjected to unsaturated heated air the saturated air at the surface of the sample is continuously forced out by this air leading to reduction of the moisture content of the sample being dried with time (Mercer, 2014)—the air velocity should be sufficiently high enough in order to efficiently sweep away the moisture at the surface; lower air velocities lead to lower drying rates.

As temperatures increase, the temperature gradient increase and this leads to transfer of the surface heat to the internal tissues of the fish resulting in an increase in the internal temperature and energization of the water molecules. The moisture ratio of the sample being dried reduces with drying time, at higher increased air velocity there is an excessive loss of excessive heat as a result of high transfer of mass and heat (Kumar et al, 2017). The rate of water diffusion, characterized by high drying rate, increases with increase in temperature, this according to Ponwiboon & Rojanakorn (2017) increases water removal from the fish during drying process since the moisture pressure inside the fish increases with increasing temperature. At a reduced moisture content of 25% (wb) fish is safe from spoilage caused by microorganisms, further reduction of the moisture content during drying to 15% inhibit growth of molds and extents the shelf life of the dried fish(Akinola & Bolaji, 2006).

The variation of air velocity had significant effect ($p<0.05$) on the drying rate of fish at both fixed number of trays and temperatures as shown in Figure 7 above. For a single tray at low temperature this variation was more at high air velocity rate of 2.8 m/s as compared to lower air velocity rate of 1.4 m/s that was insignificant. Increment in drying temperatures and air velocity hasten the drying process and as a result shorten the drying period (Ponwiboon & Rojanakorn ,2017 ; and Phanphanich & Mani 2009).

4.1.2 Influence of temperature on the relative humidity

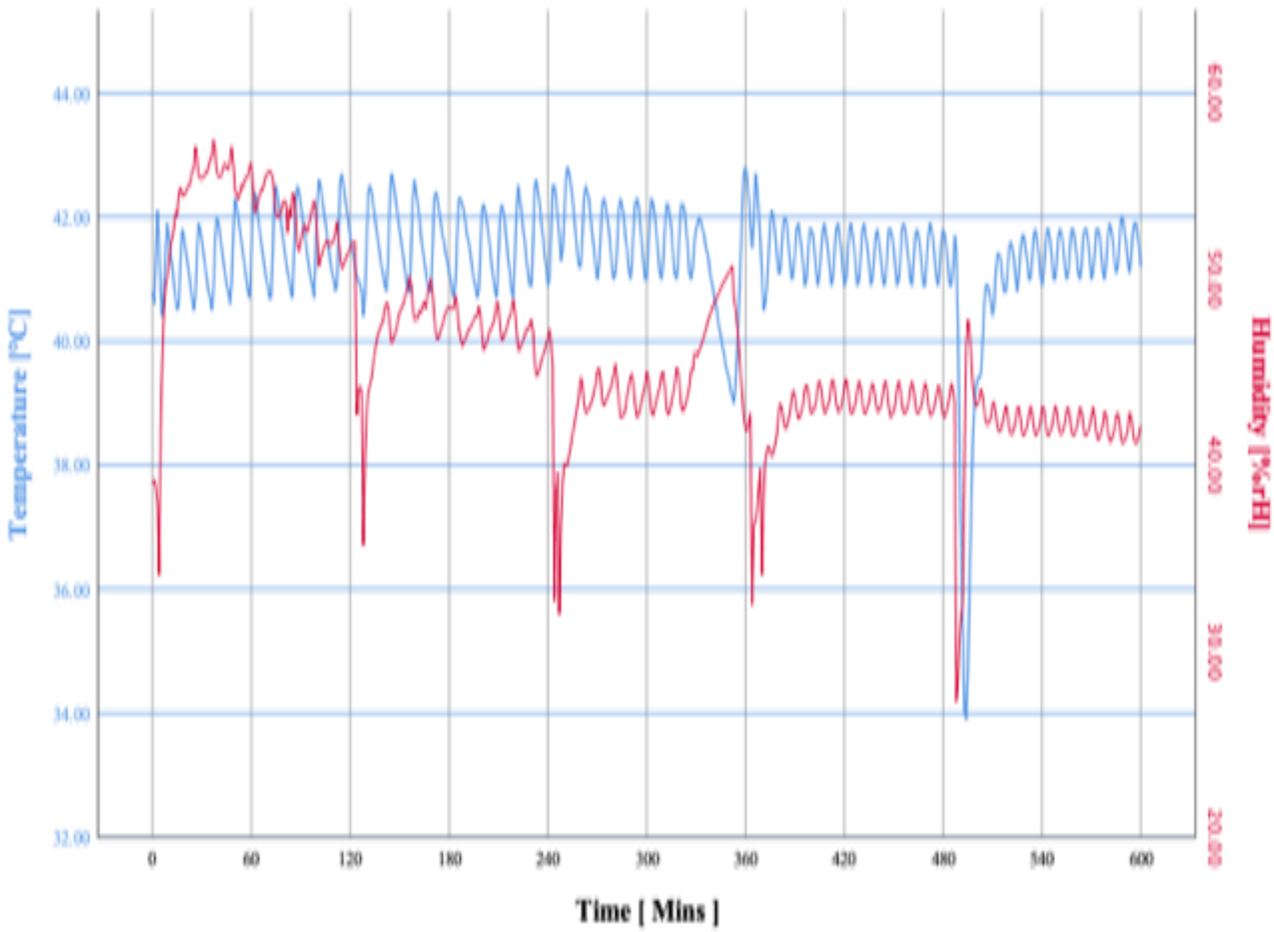

Figure 8. Influence of temperature on the relative humidity for HTHV 1-Tray

Figure 8 (above) and Figure 9 (below) illustrate the variation of both the relative humidity and temperature against drying time for Silver Cyprinid at different air velocities and number of trays settings.

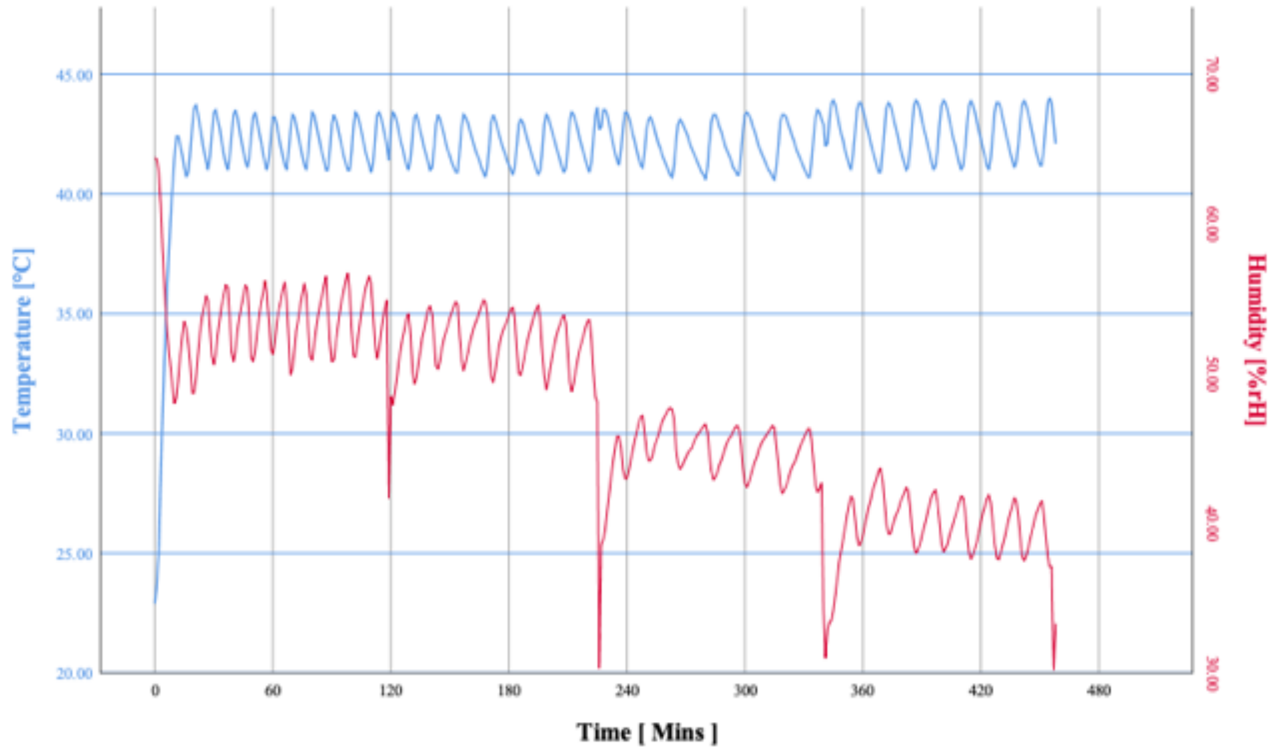

Figure 9. Influence of temperature on the relative humidity for LTLV 1-Tray

It is apparent that relative humidity decreased with increase in air temperature—the relative humidity was higher at the initial stages of the drying, this is accounted for by the fact that the fish had more moisture at the beginning of the drying process. Towards the end, much moisture is removed and the fish is much drier hence the lower relative humidity of the drier. It can also be observed that the relative humidity decreases continuously with the drying time. It was also observed that the relative humidity decreased with increase in drying air velocity within the dryer.

4.2 Characterization of batch of drying silver cyprinid integrated thermophilic energy vis-a-viz the pure electric system

4.2.1 Influence of temperature and air flowrate on drying rate of Silver Cyprinid

Figure 10 below shows the variation of moisture ratio (dry basis) of silver cyprinid for a 5-tray (av. weight: 4,000g) setting using different sets temperatures, high and low temperatures, each exposed to both high and low velocities. For the high temperature drying, the initial moisture ratio (dry basis) content was 0.821 and 0.822 g water/g dry matter for high and low velocities respectively. The total drying time was 8 and 14 hours for both experiments for HTHV and LTHV experiments respectively.

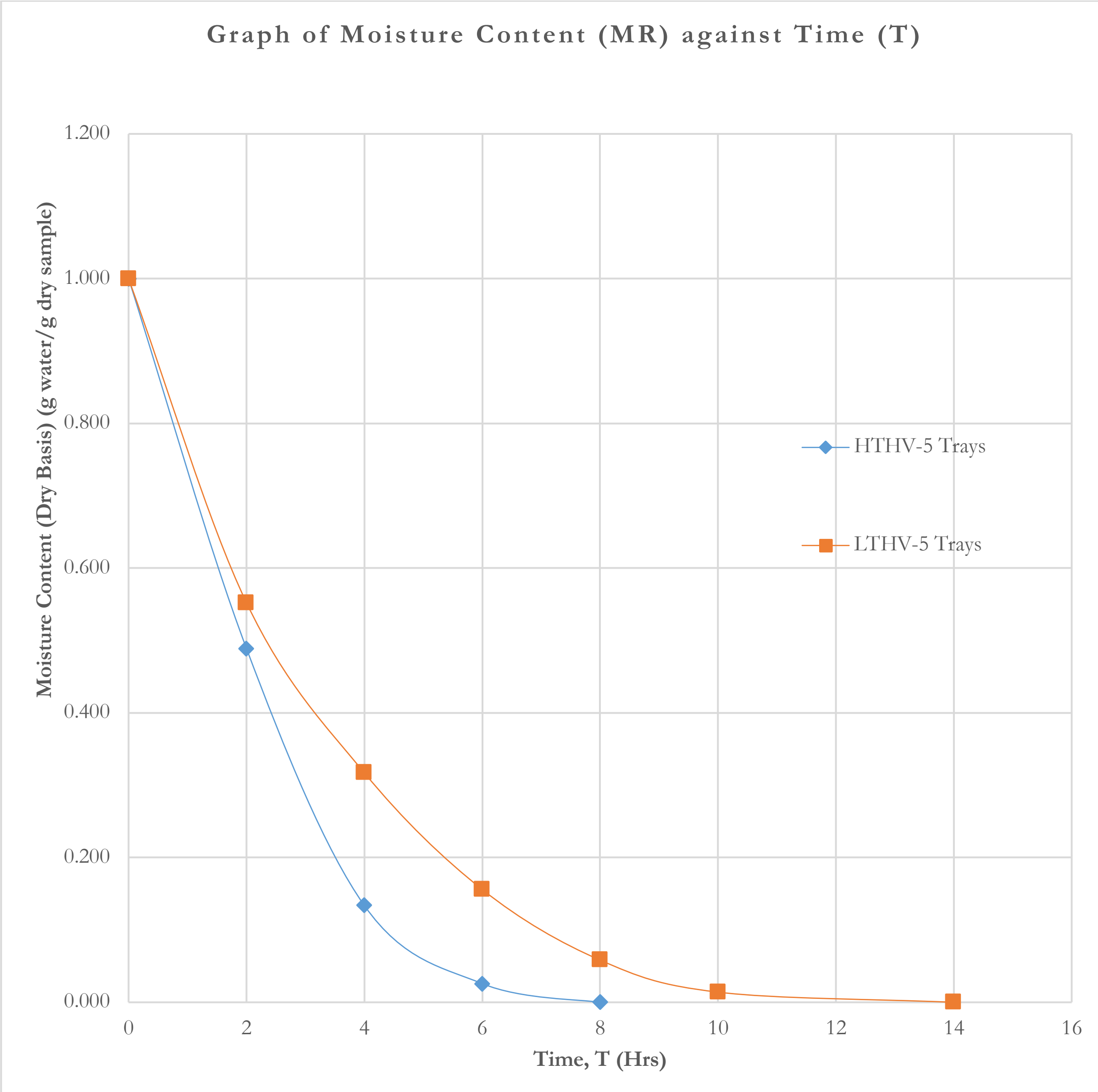

Figure 10. Changes in drying rate of Silver Cyprinid for 5-Tray Experiment

Figure 11 below shows the variation of moisture ratio (dry basis) of silver cyprinid for a 10-tray (av. weight: 8,000g) setting using different sets of high and low temperatures, each exposed to both high velocities. For the high temperature and drying, the initial moisture ratio (dry basis) content was 0.824 and 0.795 g water/g dry matter at high velocity respectively. The drying times to reach the equilibrium moisture content for Silver Cyprinid 14 and 21 hours respectively.

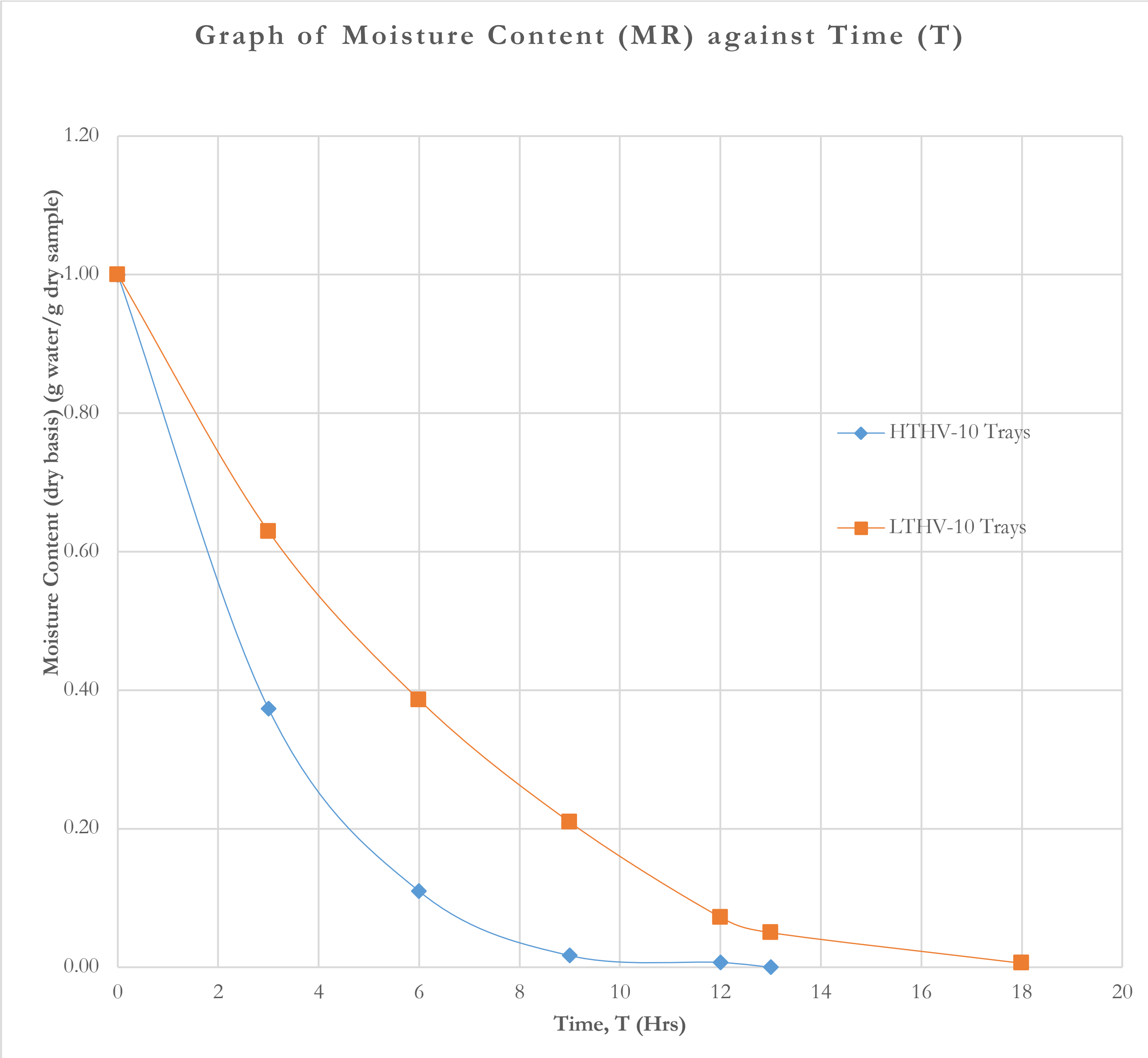

Figure 11. Changes in drying rate of Silver Cyprinid for 10-Tray Experiment

The plot of the drying curves (Figure 10 and Figure 11) reveal that the Silver Cyprinid drying process like some other animals and crops products does not show the constant rate drying period.; the drying process only occur in the falling rate period—an increase in temperature led to increased rate of drying. Hence, this confirms the conclusions about drying rates periods for fish in the previous studies done by Alfiya et al.(2019), Mujaffar & Sankat (2016) and Abdulmajid (2015).

The drying rate is faster at the initial stages of the drying process as evident by steeper drying rates curves; however, it becomes less steeper indicating a slower drying process. Generally, the drying rates increase with increase in drying temperatures. However, these drying rates decrease with time, this is an indication that temperature is a major factor affecting the drying rate of a product and that

the drying rate is being controlled by the internal movement of water within the tissues of the fish to the surface as suggested by Nielsen (2010) and Maisnam (2016) in their respective studies.
The rate of drying is faster at the initial stages evident by steeper slopes, however, the curves become less sloppy and flatten as the drying progressed, indicating less moisture in the internal tissues of the fish as suggested by Alfiya et al (2019) in their study on the influence of temperature on the rate of drying of the fish. Accordingly, increase in temperatures resulted in reduced drying times, this is in line with previous conclusions on studies carried out on drying of fish and other agricultural commodities such as Alfiya et al.(2019) for sardine, and the study by Maisnam et al (2016) on recent advances in conventional drying of foods. Consequently, raising the drying temperatures while keeping the air velocity constant significantly affected the drying rate, this is in conformity with previous experiment carried out on African Catfish by Omodara (2012).

4.2.2 Influence of temperature on the relative humidity

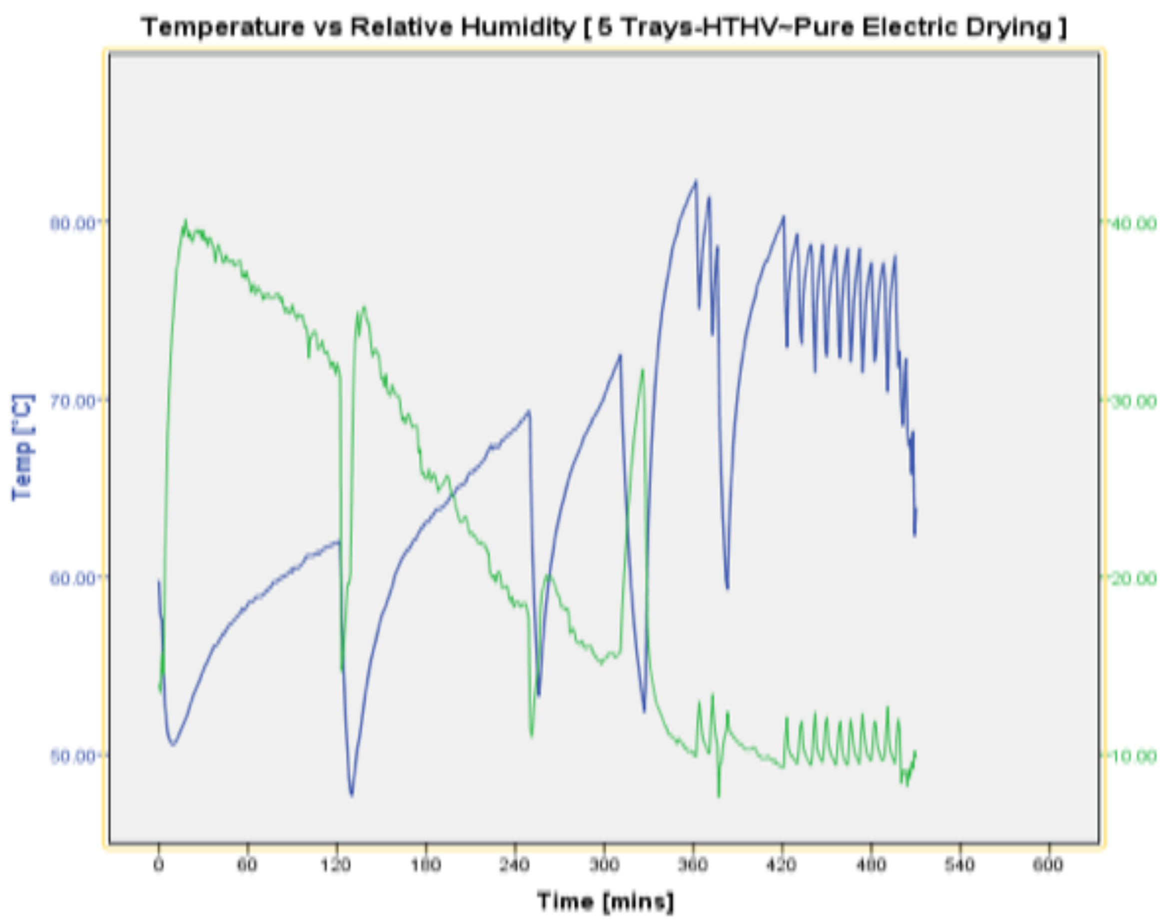

Figure 12. Influence of temperature on humidity for LTLV 5-Tray experiment –pure electric experiment

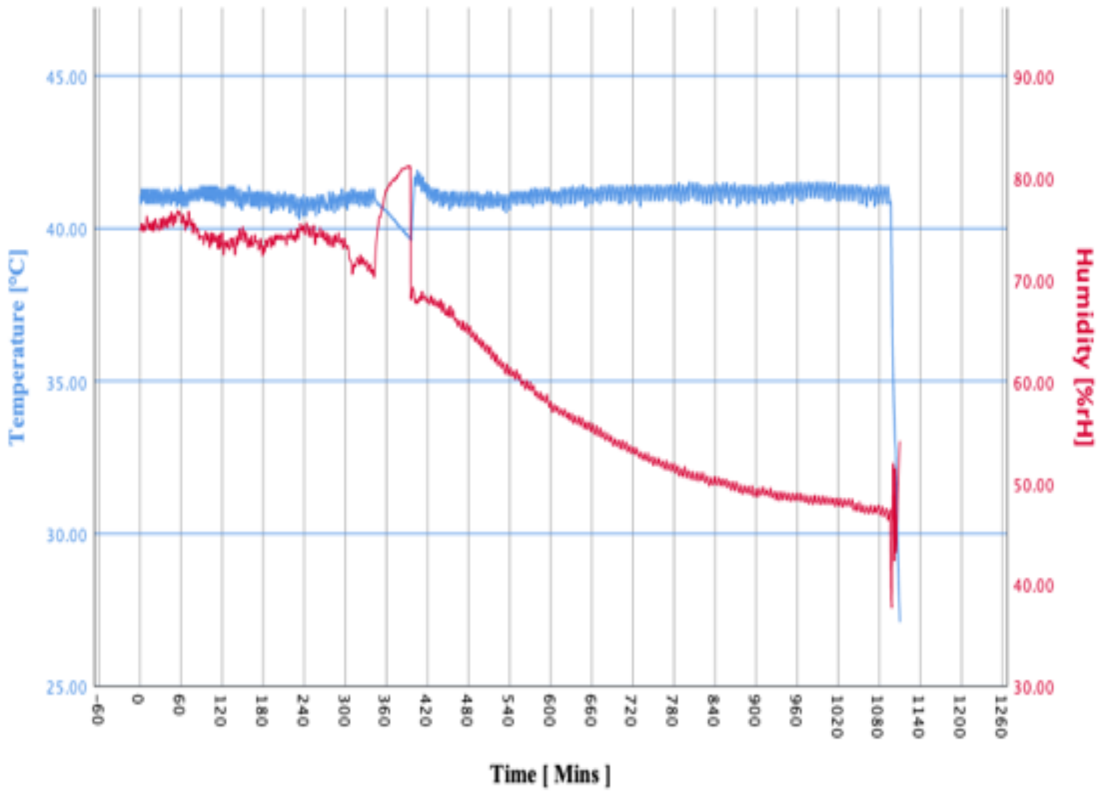

Figure 13. Influence of temperature on humidity LTLV 5-Tray experiment—electro thermophilic experiment

The relative humidity and temperature versus drying time for Silver Cyprinid at different air velocities and number of trays is shown in the Figures 12 and 13 above for the mean relative humidity for the 5-tray at HTHV and 10-tray at HTHV respectively. It is apparent that relative humidity decreased with increase in air temperature—the relative humidity was higher at the initial stages of the drying, this is accounted for by the fact that the fish was more moisture laden at the beginning of the drying process. Towards the end much moisture is removed and the fish is much drier hence the lower relative humidity of the drier. It can also be observed that the relative humidity decreased continuously with the drying time. It was also observed that the relative humidity decreased with increase in velocity in the drying process. From Figure 12 and 13, it is observed that there is a reduction in moisture content under the influence of both temperature and air velocities as drying time increased exponentially, this is in line with similar observations made by Odote et al (2015) in their study on the evaluation of the performance of hybrid thin layer solar tunnel-windmill dryer in the drying of brined and non-brined Tafi (Siganussutor) fish. The equilibrium moisture content, during drying, increased with increasing temperature intensity (Ponwiboon & Rojanakorn , 2017).

4.2.3 Influence of number of trays on drying rate

The fish dryer, at pure electric and hybrid electro-thermophilic drying system, was tested to determine whether its performance would be affected by the number of trays used—in this case the moisture removal rate for each study is used as the basis for the comparison of performance of each tray system on the drying rate. The effect of number of trays is presented using an analysis applied by Osodo and Nyaanga (2018) in their study of the effect of number of trays on the moisture removal rate. The moisture removal rates (MRRs) for each experiment of this study at different tray settings, temperature and air velocity were computed and presented as indicated in Table 3 below; this included the mean temperatures for each experimental study.

Table 3. Dryer Performance for the given number of trays

No. of Trays	Temperature (ºC)	Air Velocity (m/s)	Mean Temperature (ºC)	Drying Time (Hr.)	Initial Mass of the Wet Fish (g)	Moisture Loss (g)	Moisture Removal Rate (kg Moisture.kg^{-1} wet fish Hr^{-1})
Pure electric							
One-Tray	60	2.8	39.14	8.0	800	674	0.105
One-Tray	60	1.4	36.71	10.0	800	626	0.078
One-Tray	40	2.8	41.37	10.0	800	616	0.077
One-Tray	40	1.4	37.41	12.0	800	651	0.068
Five-Tray	60	2.8	40.26	8.0	4,000	3215	0.100
Five-Tray	40	2.8	32.23	14.0	4,000	3207	0.057
Ten-Tray	60	2.8	37.78	14.0	8,000	6458	0.058
Ten-Tray	40	2.8	41.57	21.0	8,000	6172	0.037
Electro-thermophilic							
Five-Tray	40	2.8	40.07	14.0	4,000	3182	0.057
Ten-Tray	40	2.8	40.12	21.5	8,000	5416	0.031

Table 3 above shows variation of MRRs for different tray settings, for one-tray setting at high temperature and at both low and high air velocities (HTLV and HTHV respectively), the MRR reduced with decrease in air velocities. There is a declining trend for MRR values from one-tray experiments to ten-tray experiments for both the pure electric and hybrid electro-thermophilic experiments —the MRR values for the electro-thermophilic are the least. This shows that the lower the number of trays the higher the moisture removal rate. This trend is similar to conclusion made by Aissa et al (2014) and other works as previously reviewed. The presence of several drying trays or shelves inside the drying chamber present a lower drying process, therefore, few drying trays should be used instead in order to allow the efficient circulation of air within the chamber (Aissa et al., 2014). During the drying process the moisture content varies based on the location of the individual trays in the drying chamber, the tray closest to the air inlet being the most affected, hence exhibiting lowest moisture content (Osodo & Nyaanga, 2018).

4.3 Establishment of appropriate models for the drying

Table 4 below present the estimated parameters of models used to describe the drying kinetics of Silver Cyprinid and corresponding statistical parameters—it shows the results of non-linear analysis as a result of fitting the six theoretical models with drying data. Coefficient of determination (R^2), and standard error of estimate (SEE) were chosen as the criteria to determine the superior model.
The table also shows the results of non-linear analysis of the fitting of the six semi-theoretical models to the thin layer drying data for the Silver Cyprinid at different drying temperatures and air velocities. This table show that the drying constant (k) increased as drying temperatures increased for most of the models; whereas, the values of other model parameters did not show a definite trend. The coefficient of correlation and results of statistical analyses are shown in the table too. From the evaluation criteria Coefficient of determination (R^2) and standard error of estimate (SEE), all models gave a good description of the thin layer drying characteristics of Silver Cyprinid with $R^2 > 0.99$.
The Lewis model was superior with highest value of R^2 and lowest values of SEE. Therefore, Lewis model with R^2 value of 0.998213 and SEE value of 0.001913 adequately represented thin layer drying behavior of Silver Cyprinid in dryer. Thin layer drying characteristics of Silver Cyprinid was investigated at two different temperatures and two different air velocities at pure electric drying. Thin layer drying of Silver Cyprinid predominately occurred in the falling rate period; hence, the drying process for Silver Cyprinid could be said to be dominantly driven by diffusion.

Table 4. Estimated parameters of models

S/N	Model	No. of Trays	Temp ^{O}C	1.4 m/s			2.8 m/s		
				Parameters	r^2	SEE	Parameters	r^2	SEE
1	Newton	One-Tray	40	k = 0.331302	0.991906	0.029730	k=0.522962	0.997657	0.009365
		One-Tray	60	k = 0.859997	0.998173	0.003053	k=0.92091	0.997412	0.012243
2	Page	One-Tray	40	k=0.658772, n =0.502766	0.991906	0.032568	k =0.863595, n =1.066426	0.997413	0.014137
		One-Tray	60	k =0.863595, n =1.066426	0.997413	0.014137	k=0.86360, n =1.06643	0.997412	0.01414
3	Henderson & Babis	One-Tray	40	k =0.335878, a =1.017130	0.99229	0.031565	k =0.523899, a =1.002485	0.997665	0.010395
		One-Tray	60	k =0.860076, a =1.000165	0.998173	0.003412	k=0.92061, a =0.99939	0.997414	0.014133
4	Logarithmic	One-Tray	40	k=0.294982, a =1.058326, c =-0.0493679	0.9961	0.021140	k=0.505520, a =1.013080, c = -0.011823	0.998021	0.007323
		One-Tray	60	k=0.858825, a =1.000550, c =-0.000397	0.998173	0.003920	k =0.958932, a =0.989700, c =0.009987	0.997722	0.01369
5	**Lewis**	**One-Tray**	**40**	k =0.716295, n =1.080728	0.998116	0.002422	k=0.469154, n=1.107597	**0.998213**	**0.001913**
		One-Tray	60	k=0.814294, n =1.070618	0.998205	0.002308	k =1.130381 ,n =0.737839	0.998164	0.00406
6	Diffusion	One-Tray	40	k=0.331302,a=1.000000, c =1.000000	0.991906	0.036412	k=0.522962, a =1.000000, c =1.000000	0.997657	0.01209
		One-Tray	60	k=0.859999, a =1.000000, c =1.000000	0.998173	0.003941	k =0.920912, a =1.000000, c =1.000000	0.997413	0.017314

4.4 Evaluation of the energy saving potential of the integrated thermophilic energy vis-a-viz the pure electric system.

4.4.1 Influence of mode of energy used on the drying rate

No constant drying rate period was recognized in both pure electric drying and electro-thermophilic—drying in both instances occurred under the falling rate period signaling that the only physical mechanism of moisture removal in the Silver Cyprinid tissue is through diffusion.

Comparing the drying rates at different temperature and air velocity settings, it can be observed that the drying rate of Silver Cyprinid's samples increased with increasing temperature and air velocity—the higher rates of water removal during drying were as a result higher temperatures that significantly elevate the pressure of the moisture within the tissues of the sample and the higher air velocities propagate faster removal of the moisture at the surface of the sample. Effect of increased temperatures was high on the drying kinetics when combined with the increased air velocities compared to low air velocities.

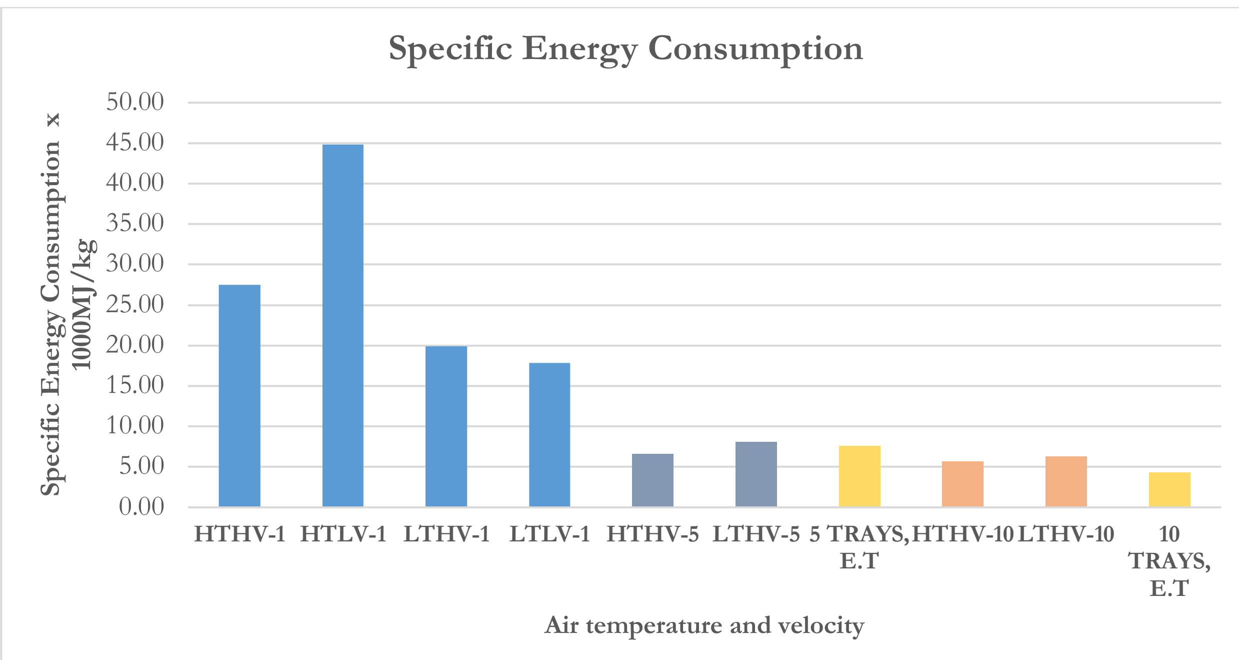

Figure 14. The specific energy consumption (SEC)

The specific energy consumption (SEC) for both pure electric and hybrid of electro-thermophilic energy sources for the experiment at different air temperatures, air velocities and tray settings are as presented in Figure 14. It can be deduced from the figure that the specific energy consumption (SEC) increased with increase in air velocity for both experiments and subsequently decreased with the increase in air temperature. For the pure electric drying, for a single tray, keeping temperature constant at 60°C and varying the air velocity from 1.4 m/s to 2.8 m/s, the SEC decreased from 44.79 to 27.52 kJ kg^{-1} of water removed. For pure electric drying at constant air velocity of 2.8m/s, for a 5 tray-setting, at a temperature range of 40°C to 60°C, the SEC for the pure electrical drying decreased from 8.05 to 6.61 kJ kg^{-1} of removed water from Silver Cyprinid. Increasing air temperature means supply of more kWh of energy to elevate the air temperature leading to increased energy consumption (Nwakuba N.R., et al, 2016b).

Table 5. Energy Consumption (MJ/kg of water removed

No. of Trays	Temperature (°C)	Air Velocity (m/s)	Average Time On (%)	Total Time (hr.)	Energy (kWh)*	Energy (MJ)**	kg of water removed (kg)	Energy Consumption (MJ/kg of water removed)
Pure electric								
One-Tray	60	2.8	64.41	8.0	5.2	18.549	674	0.0275
One-Tray	60	1.4	77.88	10.0	7.8	28.038	626	0.0448
One-Tray	40	2.8	34.04	10.0	3.4	12.253	616	0.0199
One-Tray	40	1.4	26.83	12.0	3.2	11.591	651	0.0178
Five-Tray	60	2.8	73.79	8.0	5.9	21.250	3215	0.0066
Five-Tray	40	2.8	51.25	14.0	7.2	25.829	3207	0.0081
Ten-Tray	60	2.8	72.55	14.0	10.2	36.566	6458	0.0057
Ten-Tray	40	2.8	51.38	21.0	10.8	38.844	6172	0.0063
Electro-thermophilic								
Five-Tray	60	2.8	47.63	14.0	6.7	24.005	3182	0.0075
Ten-Tray	60	2.8	30.14	21.5	6.5	23.329	5416	0.0043

*Device wattage= 1,000W

**1kWh=3.6MJ

Comparing the specific energy consumption (SEC) values for the experiments at high temperatures and air velocities it is evident that there was a decreasing trend of the SEC values as the tray settings increased. This is because with increasing tray setting the weight of the sample also increases, this is similar to the findings by Nwakuba et al (2016a) in their study on the energy requirements for drying of sliced agricultural products in which they concluded that the energy requirement of the substance being dried decrease with increasing material weight . Also, this is probably as a result of the fact that the SEC value is a ratio of energy supplied in the system and the weight of the sample. Due to gross mass of the sample to be dried, long drying periods are required leading to increased energy requirement per unit of the sample dried (Nwakuba N.R., et al, 2016b).

In conclusion, increase in temperatures and air velocities had reverse influence on the specific energy consumption (SEC) values: increased temperatures resulted in decreased SEC values; however, at increased velocities, the SEC values are inversely affected. In their study on the energy consumption of agricultural dryers, Nwakuba et al (2016a) deduced that at low temperature with high air velocity the moisture diffusivity of the sample is reduced demanding for more drying energy resulting in higher specific energy consumption values.

For the pure electric and hybrid electro-thermophilic drying at 5 and 10-tray settings at high air velocities (2.8 m/s), as shown in Table 5 above, there are lower specific energy consumption (SEC) values at the hybrid electro-thermophilic drying compared to pure electric drying for both instances. For the 5-tray setting the SEC was 8.05 kJ/kg of water removed for pure electric drying compared to 7.54 8.05 kJ/kg of water removed for the hybrid electro-thermophilic drying. Similar trend was observed for the 10-tray setting where the SEC values were 5.7 and 4.3 kJ/kg of water removed for the pure electric drying and electro-thermophilic drying respectively. Lower energy consumed per kg of water removed translate to higher efficiency compared to the higher SEC values—this means that the hybrid system had a better performance compared to pure electric drying.

The percentage energy saving was calculated on the basis of the pure electric drying. The basis for comparison was carried out by using the 10-tray experiments for both pure electric and the hybrid electro-thermophilic experiments—the electro-thermophilic experiment had a saving of 23.93% over the pure electric drying experiment.

CHAPTER FIVE

5.0 Conclusion and Recommendations

5.1 Conclusion

The main objective of this study was to evaluate the performance of a hybrid electro-thermophilic silver cyprinid dryer and more specifically: to characterize the batch-drying of silver cyprinid, establish appropriate models for the drying kinetics, and assess the energy saving potential of the integrated thermophilic energy vis-a-viz the pure electric system. The results demonstrated the untapped potential of integrating beneficial thermophilic bacteria into walls to enhance the performance and lower costs in food drying systems. From the results the following conclusions were made:

1. **Effect of temperature and air velocity:** The analysis of the results of the study present that drying process of the Silver Cyprinid occurred in the falling rate period and the constant rate period was not observed—the results also showed that air velocity had substantive impact for complete drying of the sample in both pure electric drying and hybrid electro-thermophilic drying.
2. **Effect of number of trays:** Lower drying times and higher drying rates were experienced at lower tray settings. Therefore, the lower the number of trays the higher the drying rate; the moisture removal ratio decreases with increasing number of tray settings; this is because more trays increase the load hence reduced circulation of air within the drying chamber.
3. **Thin layer mathematical model:** The Lewis model was superior with highest value of R^2 and lowest values of SEE. Therefore, Lewis model with R^2 value of 0.999981 and SEE value of 0.001913 adequately represented thin layer drying behavior of Silver Cyprinid in dryer.
4. **Energy consumption:** For the pure electric drying, for instance, considering a single tray, keeping temperature constant at 60^{o}C and varying the air velocity from 1.4 m/s to 2.8 m/s, the SEC decreased from 44.79 to 27.52 kJ kg-1 of removed water. Comparing the specific energy consumption (SEC) values for the experiments at high temperatures and air velocities it was evident that there was a decreasing trend of the SEC values as the tray settings increase. This was because with increasing tray setting the weight of the sample also increased.
5. **Effect of the mode of drying and the performance of the hybrid electro-thermophilic process:** Performance of the drying system was deduced by considering the specific energy consumption (SEC), which is a function of energy consumed and amount of water removed during drying. For the 5-tray setting the SEC was 8.05 kJ/kg of water removed for pure electric

drying compared to 7.54 8.05 kJ/kg of water removed for the hybrid electro-thermophilic drying. Similar trend was observed for the 10-tray setting where the SEC values were 5.7 and 4.3 kJ/kg of water removed for the pure electric drying and electro-thermophilic drying respectively. Lower energy consumed per kg of water removed translate to higher efficiency compared to the higher SEC values—this means that the hybrid system had a better performance compared to pure electric drying.

5.2 Recommendations

The following recommendation can be deduced from the study:

1. The higher drying performance, indicated by lower energy consumed per kg of water removed, were experienced at hybrid electro-thermophilic drying at both 5 and 10 tray-settings. The hybrid electro-thermophilic system recommendable for industrial application especially around L. Victoria in Kenya.
2. Higher air velocities above 2.8 m/s and higher trying temperatures above 50^{o}C are preferable for drying of Silver Cyprinid using the same parameters applied in this study.

Further studies on drying of Silver Cyprinid can be done on:

1. In this study, thermophilic energy was applied only to one side of the dryer. Further research is recommended on commercial applicability of the prototype and to establish the influence of integrating this energy into all the walls of the dryer;
2. Use of different compostable materials, besides the cow manure and shredded maize stover applied in this study, should also be investigated;
3. Other thin layer drying models that were not applied in the present study by studying how appropriate they can used to compare the experimental and predicted drying data of the Silver Cyprinid; and
4. Chemical composition analysis and their effect on the drying rate of the Silver Cyprinid.

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