ADDIS ABABA UNIVERSITY

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

Design, Construction and Testing of Solar Egg Incubator with Thermal Storage System

A Thesis Submitted to Addis Ababa Institute of Technology, Addis Ababa University in Partial Fulfilment of the Requirements for the Degree of Master of Science in Mechanical Engineering (Thermal Engineering)

By: Sintayehu Bekele

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Addis Ababa University

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DECLARATION

I declare that this thesis is my original work and it has not been submitted in full or in partial in this or in any other universities. And all resource that has been used to do this work is cited and acknowledged.

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ABSTRACT

Incubation is a process by which birds hatch their eggs and develop the embryo within their egg in to young off-spring. In Ethiopia where most of the population live in rural areas where there is no access to grid provided electricity, the method of hatching used were restricted to natural incubation in which the mother hen or broody hen provide the necessary condition for the development of embryo to fully developed offspring. But this is inefficient technique in terms' of production number, since the mother hen can produce limited amount of young offspring (from 10-12 per cycle).

So to solve the problem associated poultry industry hatching method, in this research design, construction and testing of solar poultry egg incubator for hatching chicken egg which can be used in rural areas of the country is discussed.

The system has solar thermal collector integrated with low power photovoltaic panel. It uses solar thermal energy to heat air inside solar collector. Air is pressurized from the environment to the solar collector by the inlet fan and gain heat inside the air chamber. The heated air from the collector flow to the incubation chamber due to pressure difference created between them by the inlet fan. Heat exchange process takes place inside the incubation chamber from the hot air to the egg maintaining the egg at 37.8^0c and 60% the optimum temperature and relative humidity required for incubation respectively.

The machine has incubation capacity of 80 egg per on incubation cycle (21 days). The amount of heat energy needed for the incubation of the specified amount of egg is 185w. Total collector area of 0.5m^2 is used for utilization of the required amount of energy. Thermal energy storage system using paraffin wax as a thermal mass. It is used to store thermal energy needed for the time direct solar radiation is not available. 20kg of paraffin wax is used as a thermal storage material and the volume of thermal storage container is $0.03m^3$ to replace the amount of 80w lost energy in the form of heat from the incubator box during the time direct solar radiation is not available.

The system is modeled using commercial software catia for part and assembly drawing and the prototype of the machine is constructed from locally available material in workshop.

Preliminary test is conducted on the prototype of the machine inside the compound of Addis Ababa University, Addis Ababa institute of technology AAU-AAiT laboratory to identify its capability to supply the necessary condition for incubation purpose. The test was conducted in the month October. The test conducted on the incubator include the variation of incubator temperature and relative humidity with the variation of ambient temperature and humidity, test on the thermal storage system to determine its capability to discharge the required amount of energy during the time solar energy is not available including the charging and discharging profile of storage with paraffin wax as a thermal mass.

On the preliminary test the thermal storage system was charged for average of 4:30 hours and it’s discharging profile investigated. From the test the thermal energy storage stores energy for 11 hours before its temperature fall below the optimum temperature of the incubator box. Preliminary test conducted in the incubator box indicate that it takes 3 hours to reach the optimum temperature after opening the door of the incubation chamber and the temperature and relative humidity of the incubation chamber is highly dependent on the temperature and relative humidity of the environmental air.

The result obtained from of the preliminary experimental test is promising. And it can solve the problem of the village poultry in rural areas where there is no access to grid provided electricity.

Key words: - incubation, poultry, humidity, solar collector, hatching

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LIST OF ABBREVIATION AND SYMBOL

PCM	Phase change material
PV	Photo voltaic panel
GDP	Gross domestic product
DC	Direct current
Q	Heat
Q_{tot}	Total heat
Q_a	Heat of air
Q_e	Heat of egg
Q_C	Heat loss by conduction
Q_v	Ventilation heat loss
L	Length
W	Width
H	Height
M	Mass
β	Tilt angle
ρ	Density
C	Specific heat capacity
C_s	Specific heat capacity of solid state
C_l	Specific heat capacity of liquid state

T	Temperature
T_m	Melting temperature
P	Pressure
T	Thermodynamic temperature
T_a	Air temperature
Z	Compressibility factor
R	Molar gas constant
ϕ	Latitude
θ_Z	Zenith angle
δ	Declination angle
Ө	Angle of incidence
a_s	Solar azimuth angle
ω_s	Sunshine hour angle
ST	Solar time
S	Absorbed solar radiation
A_c	Area of glass cover
S	Absorbed solar radiation
U_l	Overall heat loss from the collector
T_c	Collector temperature
T_a	Ambient temperature

K_T	Clearance Index
I_T	Total hourly radiation
Q_U	useful energy gain of collector
η	Efficiency
R_e	Reynolds number
D_h	Hydraulic diameter
h	Convective heat transfer coefficient
p_a	partial pressure of dry air
p_v	partial pressure of water vapor

CHAPTER ONE

1.1 Introduction.

Ethiopia is one of the highly populated country in Africa. The total population is estimated to be 104.9 million and growing estimated rate of 2.5 percent according to 2019 report [1]. Most of the population lives in rural and none electrified part of the country [2]. These rural communities of the country depend on agriculture for their sustenance. The agriculture sector employs (80-85) percent of the population and contribute 40% to the GDP of the country and the livestock contribution to the agricultural GDP estimated 20.7 % [1]. Poultry production contribute significant share and 80% of the poultry product are contributed by village poultry production [3].

Village poultry production is an old and traditional practice which involves production of small folks of chickens using scavenging feed resources. It contribute to the livelihood of poor households economical as a starter capital, as a means to recover from disaster and as an accessible protein source [4].

This contribution of village poultry is considered as an opportunity because if the suppliers of poultry are small scale farmer instead of large scale commercial companies, poultry will contribute to poverty reduction [4].

In contrast to its multiple role in livelihood improvement for the poor, village poultry in Ethiopia receives limited attention in research and development effort and it is facing many challenges [4].

The method of hatching is one of the problems that is limiting the production efficiency of village poultry industry. Natural incubation is used for hatching purpose. It is a method of using broody hen for hatching young off-spring. It is common and old practice in Ethiopia [5]. In the process of natural incubation the mother hen or broody hen provide the required humidity, temperature and turning by natural way until the embryo develop and hatch.

The profitability of poultry farm using natural incubation depend on the hatchability of brooding hens (dependent on genetics) and the degree of chick’s survivability [5].

Artificial incubation is a process of controlling temperature, humidity and turning artificially as best as the broody hen can provide. However, despite the fact that the percentage of hatchability from local broody hen is more efficient than any type of incubator, artificial method has following advantage:-

- Chickens are hatched whenever required rather than waiting the hen to become broody.
- Large number of chickens can be hatched at a time [4].

Absence of modern poultry egg incubator which can be used for rural and non-electrified part of the country is one of the challenges. So the need in advancement of technology for the improvement of hatching method in rural area is one of the vital issues that have to be undertaken. Since the natural incubation is inefficient interms of production quantity some other alternative hatching methods should be considered.

One of the alternatives hatching method is using photovoltaic panel to power electric egg incubator that are currently available in market. This requires arranging larger array of solar panel and components such as inverter to convert the DC current from the panel to ac current. This makes using photovoltaic panel for heating in electric incubator expensive and unaffordable for poor farmer located in rural areas.

Thus, to avoid problems of those type of equipment, design, construction and testing of small scale, efficient and not expensive machine utilizing solar energy is considered. Small scale incubator is considered to insure affordability to small scale farmer and help to improve village poultry production.

Chicken egg incubation is simple process, but it requires regular controlling of temperature and humidity. Using a solar system to power the incubator can be necessary if it is far moved from grid provided electricity or home power is unreliable. The system needs to be able to provide energy as needed to avoid losing of batch of eggs [6].

Solar energy is one of the type of renewable energy resources that could be used economically to fulfill increasing energy demand [7]. The solar energy is considered the best alternative source of energy because, it is there in plenty and free of charge, it is non pollutant and clean, and it is available everywhere.

The available solar energy depends on position of sun in the sky, Weather conditions especially the clouds and the geographic location of the place. Since Ethiopia is located near the equator there is abundant amount of solar energy which can be used from low temperature to high temperature heating and cooling process.

1.2 Background and Justification of Study

In rural areas of Ethiopia natural incubation is used for hatching chicken. In natural incubation the broody hen provide the necessary condition for hatching by sitting on the egg. It provides the required humidity and temperature level by natural way. It takes 21 day for the embryo to develop in to fully developed chicken [8]. The maximum number of egg one hen can incubate per one cycle ranges form (10-12). This type of production process is inefficient in terms of production number [9].

On the other hand electric egg incubator used in a place located near small town and urban areas are efficient. However, since these type of incubator work with grid electricity there is risk of death of embryo during power outage unless some additional power storage or source is used to fill the gap. In addition to that, it cannot be used in rural areas where there is no access to grid provided electricity.

Photovoltaic power source can be used for heating of electric egg incubator. But using photovoltaic system for heating requires arranging as many PV panel to get the required amount of power and large battery for storage of power for the sunset hour of the day(the time solar radiation is not available), this result in additional increase in cost of machine as well as production cost [6].

The following problem is identified as a research gap from discussed different literatures, the inefficiency of natural incubation in terms of production number, the artificial electric incubator is limited in its application. It is used only in electrified part of the country or on-grid application. As well as loss of batch of eggs during power outage for long period of time unless additional power source is used. Using photovoltaic panel to drive electric egg incubator is expensive. Due the above stated reasons design manufacturing and testing solar thermal poultry egg incubator with proper control mechanism for regulating the conditions required for hatching is mandatory.

Thus to solve the problem stated on the natural incubation process and artificial incubation machine, an alternative incubation method is considered. In this research solar egg incubator with paraffin wax as thermal storage system and air as a working fluid is considered.in this work. Integrating solar thermal system with low power PV panel makes the work significant and unique.

Thus it is expected to have the fallowing merits.

- Since it driven by solar energy there is no expense for power used during incubation process.
- It increases the production efficiency by increasing the number of chicken produced.
- Since it uses solar energy it is environmental friendly.
- Since most of the part of the machine is constructed from available cheap material its cost is not expensive.
- It can be used everywhere solar energy is available.

1.3 Problem Statement

In the village poultry industry of Ethiopia natural incubation is used for hatching young chicken. Natural incubation is a process by which the mother hen or broody hen take care-off the egg to be hatched and provide the necessary condition for the development of the embryo within the egg to fully grown off-spring. The broody hen provide the condition by simply sitting on the egg and provide the required heat and humidity from her body by contact. Heat is transferred from the body of the mother hen to the egg by conduction. Since the mother hen can hold limited amount of eggs for one cycle of incubation period, natural incubation is one of the factor that limit the production efficiency of village poultry industry of the country.

Artificial egg incubation is a process of replacing natural incubation by man-made machine which can give necessary condition to the egg .Electric driven type egg incubators are available in market but this machine cannot be used in rural areas where there is no access to grid electricity supply. Scholars bring an alternative of using photovoltaic panel for operating electric egg incubator. However, using photovoltaic panel alone for heating electric egg incubator needs arranging large arrays of panel to obtain the needed amount of energy and battery's to store energy needed for the time solar radiation is not available. Since photovoltaic panel is expensive it makes the cost of the machine unaffordable to the rural low income poultry producer.

Another alternative used for incubation is using solar thermal energy for artificial incubation purpose. Solar thermal collector with thermal storage system is suggested by some scholars but using solar thermal energy alone needs continuous attendance of operator for the control of incubation parameter needed for successful hatching.

Hence, development of an alternative hatching method is vital issue to solve the problem of village poultry industry in rural areas of the country with an affordable cost and needing small operator interaction. So the aim of this paper to design, construct and test solar thermal egg incubator integrated with low power and low cost photovoltaic panel. It uses solar thermal energy for heating and low power solar panel with battery used for house hold electrification for control purpose. It should benefit the rural community living without grid provided electricity.

1.4 Objective

1.4.1 General Objective

- The general objective of this research is to design, construct and test solar egg incubator which can be constructed from locally available material and with affordable cost for rural poor community in Ethiopia.

1.4.2 Specific Objective

- Gathering of data(weather data and literatures) estimation of required energy
- To design an incubator and collector with thermal energy storage analytically.
- Geometric modeling of the collector and the incubator using catia software.
- Construction of the collector and incubator.
- Preliminary experimental investigation on the incubator.

1.5 Delimitation

In this study design, construction and testing of solar poultry egg incubator with proper mechanism for control of incubation condition is done. It uses solar thermal collector with thermal storage for supplying the heat and low power PV panel to control temperature and humidity.

However, this research has the following delimitation.

- Design construction and testing of the machine is done in Addis Ababa using solar data's obtained from national metrology agency of Ethiopia for Addis Ababa. But the machine should be used in rural areas where there is no grid provided electricity. So that, there may be variation in intensity of solar radiation as well as atmospheric condition. This may cause reduction in efficiency of the machine when it is used in other areas or it may need correction and re-design.

- Due to certain an expected intermittency in availability of solar radiation, the machine may not be used if sunlight is not available for long period of time or solar radiation is not available for period more time than the time thermal storage system can store.
- This machine is designed considering the available solar radiation from the beginning of September to the end of July. Solar radiation is not available for the rest of the month of the year.

1.6 Research Organization

The research paper is organized into five chapter

Chapter one

The general introduction of the research, background and justification of the study, statement of the research problem, and objective of the research, the scope and delimitation of the research is discussed in the first chapter.

Chapter two

The background of the research, the historical evolution of the artificial incubator, types of artificial egg incubator, the condition required for incubation, review and summery of literature on what has been done in this area of study is discussed in the second chapter of the research.

Chapter three

The third chapter of the research discuss about methods and material used to achieve the objective of the research. Assessment of total energy demand for incubation, design flat plate collector with thermal storage system, and selection materials and other auxiliary component for construction of the prototype is done. Methods used to construct and test the machine is also discussed in this part of the research.

Chapter four

This part of the research discuss about the result obtained from the analytical design and preliminary experimental test.

Chapter five

The final part of the research discuss about the conclusion drawn from the result obtained and gives recommendation for future work to be done for further improvement in this field of study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Use of natural incubation for hatching purpose in rural areas of Ethiopia is one of the bottleneck or factor that result in increase in cost of poultry product due to its drawback of small production number.

Artificial egg incubation is a process of replacing broody hen by artificial or man-made machine which can supply the egg with the necessary incubation condition as best as the broody hen can provide. It has long history of practice in world poultry industry. Currently advancement in technology is bringing very complicated and efficient hatching machine to the world poultry production industry.

In the evolution of poultry industry many works has been done by scholars to improve the incubation process. The identification of incubation condition that affect the hatchability and methods used for heating, control of incubation conditions such as temperature, humidity, turning, ventilation and the type of energy sources used for heating an incubator were the areas of improvement in research done in past.

This part of the research presents literatures related to incubation that had been done by scholars in the past, such as historical evolution of an artificial egg incubator and conditions required for incubation,. The type of artificial egg incubator and type of energy used for incubation.

2.1.1 Background of Artificial Incubation

Artificial egg incubation is an old practice which lasted for thousands years. Egyptian and Chinese are credited with originating artificial incubation procedures paniago [10]**.**

According to paniago [10] artificial egg incubation was started by Egyptian before 3000 years ago**.** The ancient Egyptian egg incubator consists of large building made up of mud with a series of rooms with central corridor for passageway. Shelves are located in the top of each small room for burning straw, camel manure or charcoal to provide heat to the egg. In addition vents are located on the top part of the room to remove smoke and to provide light. Eggs were turned twice a day manually. The temperature of the room was controlled by controlling the strength of the fire and by opening and closing the man hole as well as the vents located on the top of the room .Control of another parameter humidity was done by distributing moist jute when it is necessary. No measuring device was used to measure temperature and humidity. It was done by hatchery feeling and sense of touch that live inside the building.

Aristotle, the Greek philosopher, writing about poultry at around 400 BC, describes a similar method to Egyptian paniago [10]**.**

The Chinese developed method in which they burned charcoal to supply heat Benjamin. N et al [11] with the same concept as that of Egyptians. They also utilize the concept of heat transfer. After the chicken embryos developed, they started to produce increasing amounts of heat and consequently they did not need added heat [10].

2.1.2 Development of Modern Incubators

In the mid-1600s Egyptians expert was taken to Europe to build and operate Egyptian type incubator. But the project failed due to adverse conditions in Europe during winter time in opposite to warm and constant condition in Egypt which makes the method unsuccessful [10].This failure bring an objective of developing more complicated machine.

In china, incubator houses with double walls of mud, a fire room, and several compartments each holding about 6000 hens eggs were developed in 1840 and large ones have been used since 1910;some commercial models have trays for as many as one million eggs. The first commercial incubator was manufactured by Hearson in France in 1881 [10].

2.1.3 Types of Artificial Egg Incubators

Incubators are classified as still air, forced draft and contact type based on how air is circulated inside the incubation chamber.

2.1.3.1 Still Air Incubator

This are the most basic types of incubators consisting of a heating element, temperature controller, and tray which is used to hold egg, thermo-hygrometer to measure temperature and humidity. The air inside the incubation chamber of still air incubator is circulated by natural convection or due to temperature gradient. As air is heated it expands and rise to the top of the incubator. The amount of air flow depends on the temperature difference between the inside of the incubator and the outside environment. The lower the outside temperature the higher the air flow. Since the hot air flow to the top of the incubator box different temperature should be measured at different levels, so the egg should be placed on level surface and of all the same size [12].

2.1.3.2 Forced Draft Egg Incubator

This was developed to overcome the temperature gradient problem inside still air incubator. In this type of incubator fan is used to circulate air throughout the incubation chamber. It gives more uniform temperature distribution than the still air type egg incubator. The eggs can be placed at different levels and the egg can also vary in size. Using forced air incubator allows accurate temperature and humidity measurement and control [12].

2.1.3.3 Contact Egg Incubator

This type of incubator resemble natural incubation or incubation using broody hen. In natural incubation the broody hen provide the necessary warmth by contact rather than surrounding the egg with warm air. In contact egg incubation heat inter the egg over small brood patch, therefore this region is warmer than other region which result in temperature difference over the egg which in turn result in loss [12].

Researches contribute significant role in improvement of hatching in world poultry industry. The areas of study is not limited to the replacement of natural incubation by the artificial incubation but it includes the identification of factors or parameters needed for incubation effect of change of this factor on the efficiency of the incubation.

French [13] used a simple model to describe relationship between the temperatures of developing embryo, incubator temperature, heat production of embryo, thermal conductivity of egg and air surroundings the egg.

Harb et al [14] designed and constructed a small electric poultry egg incubator at Egypt agricultural engineering research institute. It was fabricated from available cheap material and it is used to utilize to produce a chick for small scale farmer. Automatic thermostat is used to maintain the temperature at 37^0c and an electric heater. The incubator capacity was 60 eggs. Thermometer is used to measure the temperature inside the incubator above or below the center of the egg. Humidity or the moisture level inside the incubator is controlled by a pan of water under the egg tray and adding warm water as needed. In case more humidity is required increasing the size of the pan or adding wet sponge to the incubation chamber. Humidity can also be adjusted by increasing or decreasing ventilation.

Okpagu and Nwosu [8] discuss the design and development of an incubator that can be used for different types of egg with in the temperature range of $35\text{-}40^0$c. This system uses automatic sensors which measures conditions of the incubator and turns to suitable conditions of the egg. This work uses electric bulbs for heating whereas water pan and fan for controlling humidity and ventilation. DC motor was used to rotate iron rod at the bottom side and automatically change position of the egg. The entire element is controlled using Microcontroller and these works provide good result with grid provided electricity.

Paravin kalumarme et al [15] done the same work heated by electricity and parameters are controlled automatically.

Mod Badly Ramble et al [16] worked on electric power operated incubator for various type of egg with conveyer rotating system. Direct current geared motor with low speed was used to rotate chained steel material at the bottom and automatically.

Kanu Ozioma et al [4] designed and constructed micro base solar incubator. It consist of a solar collector which heats water that in turn heats an incubating chamber for the process of fowl hatching.

Bolaji [17] designed, fabricated and evaluated the performance of solar poultry egg incubator. The incubators consist of solar collector with built in thermal storage system for the capacity of 100 eggs. The solar collector collects solar energy during the day and the thermal storage system to store thermal energy for night time. The collector with thermal storage system is connected to the incubation chamber using air duct. Monitoring and control of incubation parameter such as temperature, humidity and turning is done manually.

Ahiaba [18] on designed a Passive Solar System for Poultry Egg Incubator. The prototype of the machine is shown on Figure 2.1. It has means of collecting solar energy using plane window glass, a means of storing the collected energy using an 80 mm concrete slab serving as the thermal mass and a means of transferring the stored energy using a heat exchanger and direct dissipation from the thermal mass into the incubating chamber where the fertile eggs are to be kept for the purpose of incubation. One of the drawback of this system is since it is passively heated it is subjected to fluctuating weather condition. It needs regular controlling of incubation parameters, in which all are controlled measuring by analogue thermometer and hygrometer and turning manually.

Figure 2.1. Passive solar incubator [18]

Javier Garcia Heiro et al [19] designed and evaluated the performance of hybrid electric avian egg incubator supported with solar thermal energy under detailed monitoring. An evacuated solar collector with an absorbing area of 0.99m^2 and 163 L of water accumulation (with an auxiliary 80 L water tank) was coupled to the original emergency cooling system of the incubator. The hybrid system, using an automated control system, shows higher thermal stability than the standard control system of the incubator. The system comprises two heating resistor working simultaneously that are controlled by a temperature controller. Additionally, the incubator is equipped with an emergency cooling coil that operates in case of overheating and consists of a heat exchanger fed by water. Heat exchange between the incubator and other element is forced by ventilation by means of a fan located in front of the radiating element. The emergency cooling system was modified to be fed with hot water from solar panel, allowing for the combined electrical and solar heating of the incubator and the circulation of water in a closed circuit.

Kifilideen L.Osanyinpeju et al [6] designed, constructed and tested solar photovoltaic chick egg incubator in Nigeria. This was done to supply an incubator with uninterrupted power and keep the incubator in an operation. The main component of the work was the incubating chamber and the solar power supply system. The developed solar incubator has capacity of 150 eggs. The size of the components of the solar power supply system was based on the amount of energy needed and the duration of usage for the amount of the eggs to be incubated.

K.G.mansaray [20] fabricated and evaluated the performance of solar photovoltaic egg incubator at university of Sierra Leone and result shows that percentage of fertility and hatchability of eggs were 43.3% and 23.1%, respectively.

T.suriwong, et al [21] developed prototype of thermoelectric egg incubator integrated with thermal storage system and photo voltaic panel for the capacity of incubating 24 egg within 21 day of incubation period. Photovoltaic panel is used as a primary supply power to thermoelectric module for providing the necessary heat and relative humidity. This system can be used for off-grid application and provide method of heating and cooling by dc electric power from solar panel. The thermoelectric module has no environmentally harmful fluid like chlorofluorocarbon. They are reliable and environmental friendly. However, using this system requires purchasing thermoelectric module as well as photovoltaic panel which result in costly product.

2.2 Conditions of Incubation

Incubation conditions are factors that affect the hatchability of chicks. This are conditions inside incubator in which the egg to be hatched is subjected. These conditions should be controlled with in the required range to avoid loss of batch of eggs.

2.2.1 Heat Perceived by Embryo

Heat perceived by the embryo is dependent on the surrounding environment of the egg.

There are 4 main factors that determine the heat perceived by the embryo

- Shell conductance.
- The difference in temperature between the egg and its surrounding environment
- The calorific capacity of the air.
- Air speed [13].

2.2.1.1 Shell Conductance

Under aerobic conditions, the principal source of energy for the embryo comes from the lipids contained in the yolk. Their metabolism provokes the production of water and CO_2 which must be evacuated through the shell pores. Conductance is the capacity of the shell to diffuse the necessary gasses for the Metabolism, O_2 and its by-products (H_2O and CO_2).This depends on the functional surface of the pores and shell thickness and is independent of the incubation conditions. It is not an expression of the speed at which gas can be exchanged. This depends on the differences in concentration between the egg and its immediate environment [13].

2.2.1.2 The Difference of Temperature between the Egg and Its Environment

The speed at which heat is exchanged essentially depends on the difference between the temperature of the egg and its immediate environment. Since the production of heat from the embryo is inferior to the loss of heat by evaporation during the first 8-9 days of incubation, the set point temperature of the incubator should be higher than that of the embryo. Inversely, from the 9^{th} to 10^{th} days of incubation, the heat production from the embryo is greater than the loss of heat by evaporation. The set point temperature of the incubator should therefore be lower than embryo temperature H. Decuypre and Michel [22].

2.2.1.3 The Calorific Capacity of the Air

The calorific capacity of the air is determined by relative humidity. When air is dry, it is a poor conductor of heat. Humid air allows more uniform distribution of temperature within a machine. It is better to use slightly higher humidity at the start of incubation to distribute heat more evenly, which produces a more uniform development of the embryos. As an alternative to the permanent use of humidifiers, the increase in humidity is best achieved by closing the ventilation outlets, which forces passive evaporation from the eggs themselves French N.A [13].

2.2.1.4 Air Speed

The capacity of the egg to exchange heat with its environment depends on its mass, shell conductance and air temperature surrounding it. This is known as the thermal conductance of the egg. This is extremely dependent on the air speed around the egg. French [13] discussed that the air surrounding the egg can be a barrier to heat exchange. This barrier may be up to 100 times more effective than the egg itself.

It is therefore important that the air speed surrounding the eggs is sufficient to disrupt the air barrier around the egg. Since air speed has a negligible effect on water loss during incubation, it has no upper limit for incubation process. Within the same incubator, however, air speed is variable (from 0.2 m/s up to 4m/**s**) and the differences in temperature between the egg and its Environment is higher when air speed is low [13].

2.2.2 Temperature of Hatching

According to French [13] the temperature experienced by a developing embryo depends on three factors, incubator temperature, ability of heat to pass between the incubator and the embryo as well as metabolic heat production of the embryo itself.

Shell temperature is a good indication of the temperature perceived by the embryo (differences between the shell temperature and the embryo are often not more than ±0.2. It is possible to adapt the incubator temperature according to the recorded shell temperature.

French N.A [13] draw the following conclusions from his research.

- For most chicken species, the optimum incubation temperature is found between **37.0-38.0°C,** although it is even possible to hatch under temperatures that vary between **35.0-40.2°C.**
- Embryos are more sensitive to high temperature; rather than low temperature.
- The effect of sub-optimal temperature depends on the intensity and duration during the period that it occurred.
- Embryos appear more sensitive to sub-optimal temperature at the start rather than the end of incubation.

Lourens. A et al [23] achieved better hatch results and chick quality when shell temperature was maintained at 37.8°C during the complete incubation period. According to these same researchers insufficient temperature during the first week delayed embryonic development and can also compromise the chick's thermoregulatory systems during the first 7 days after hatching. In contrast, high temperature at the end of incubation 38.6°C.Appears to increase the chick's thermo-tolerance, thus increasing their tolerance to heat stress later.

This rather tight tolerance between minimum and maximum temperature may be too simplistic for what is a more dynamic situation. It may be possible to allow greater temperature fluctuations at specific stages of incubation.

2.2.3 Humidity during Incubation

The amount or concentration of water in the egg and the chick is similar. It is within the range of 74-75% for egg. The amount of water loss during incubation process is the same as the amount of water produced by metabolism of lipid contained in the yolk which is 18%.

G.K Baggot [24] noted that in most chicken species, total water loss of 20% relative to the initial egg mass results in a similar water concentration in the chick as in the egg.

R.Meijerhof [25] indicated that production of metabolic water represents 12 to 14% of the initial egg mass and that at least 9 to 10% of this water should be eliminated to allow for the formation of an air space sufficient to engage pulmonary respiration. The fact remains that egg weight loss during incubation is essentially linked to water loss and that this is only dependent on the shell conductance and ambient humidity. No other factor is involved.

N.A French [26] has however found that excessive levels of humidity (75-80%) provoke an increase in embryonic mortality during the first 10 days of incubation. He also observed that the hatchability remained satisfactory when the humidity varied between 40 and 70%, with an optimum level of 50%.

Water loss during incubation only has negative effects on hatch results. If the humidity exceeds the optimum level and is closer to the extremes of the margins of water loss. The levels of humidity should therefore be adjusted to be within the recommended range of water loss. In practical terms, humidity should be set between 50 and 55% from the 1st day to 18th day and 65%for the last three days of incubation [13].

The air cell increases in size during incubation at a rate that depends on temperature and humidity as moisture evaporates from the egg [13].

Figure **2.2** shows the normal size of an egg's air cell at 7, 14 and 18 days of incubation.

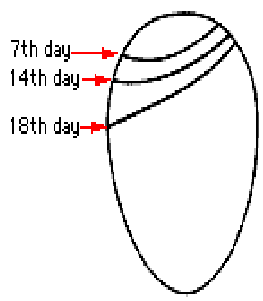


Figure 2.2 Size of air space at different days of incubation period [12].

2.2.4 Turning

As the embryo develop in yolk, it initiate part of the yolk to lose weight and float upward. It floats continuously deforming inner membrane until it touch shell membrane. If the embryo touch the shell membrane the embryo will die by sticking to it. Turning egg prevent the yolk from sticking to shell Membrane. Four method of turning are widely used in today's poultry industry.

2.2.4.1 Tilting Tray

In most commercial incubator, incubators are provided with plastic egg tray holding the egg vertically as shown on Figure 2.3. The small end of the egg is turned down. The eggs are turned at an angle of 45^0 from the vertical [12].

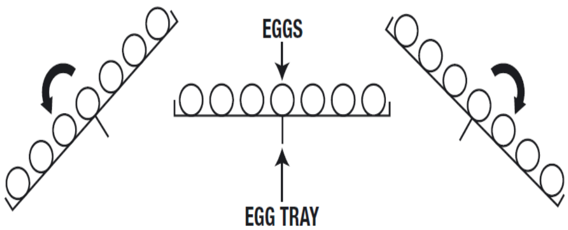


Figure 2.3 Tilting tray [12]

Experiments showed that an angle of turning of 15° (relative to the vertical) leads to embryonic mortality in the second part of incubation 10 times greater than when eggs are turned at an angle of 45^0 [26]. Turning increase hatchability by preventing adherence of embryo to shell of the egg. Eggs should be turned from 3-5 times a day from 2^{nd} day to 18^{th} day Bolaji [17].

2.2.4.2 Moving Floor

Moving floor egg turning mechanism is shown on Figure 2.4. In small and single layered incubator the egg lie on horizontal conveyor moving from side to side. When the conveyor move it make the egg to rotate. The eggs are prevented from lateral movement by fixed divider so that the egg rotate [12].

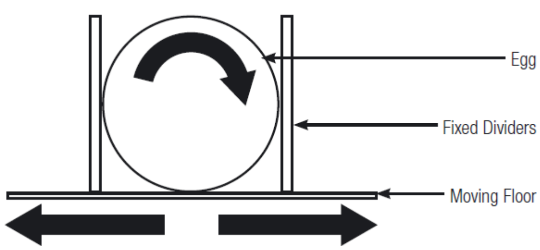


Figure 2.4. Moving floor [12]

2.2.4.3 Rollers

In this type egg is place on the roller and it is rotated by moving tray. As it is shown on Figure 2.5 when the roller rotate it make the egg turn over [12].

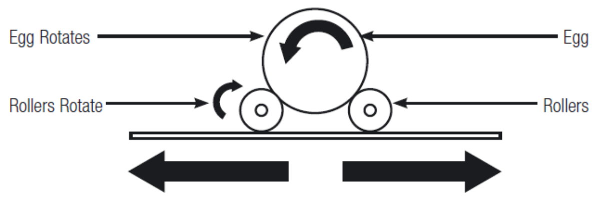


Figure 2.5. Rollers [12]

2.2.4.4 Through and Channels

In this type of incubator egg is placed inside channels and channel is rotated in order to rotate the egg [12].

2.3 Solar Collectors

Solar collectors are mechanism used to harvest energy emanating from the sun [7]. Solar collector can be classified based on the type of application used for.

Generally solar collection technologies are classified into two board classification.

- Solar photovoltaic.
- Solar thermal.

2.3.1 Photovoltaic Solar Collector

Photovoltaic collector are the type of energy harvesting mechanism that generate electric power from solar radiation using semiconductor that exhibits photoelectric effect. Photovoltaic power generation employs solar panel composed of solar cell containing a photovoltaic material.

Materials presently used for photovoltaic include mono crystalline silicon, Polycrystalline silicon, amorphous silicon, cadmium telluride, copper indium gallium and solenoid supplied. Photovoltaic panels are expensive in cost and it may need to arrange large array of panels to obtain required amount of power for the purpose it is intended for Meissen [27].

2.3.2 Solar Thermal Collectors

A solar thermal collector is a special kind of heat exchanger that transforms solar radiant energy into heat. In solar collector, energy transfer is from a distant source of radiant energy to a fluid (working fluid). Generally there are two board classifications of solar thermal collector based on geometry A.Beckman [7]

1. Concentrating solar collector or sun tracking collector (CSC).
2. Flat plate collector or none concentrating or non-tracking (FPC).

2.3.2.1 Concentrated Solar Collector (CSC).

Concentrating solar collector system use mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Large heat is produced when light is concentrated to a small area [7].

Concentrating solar collector attaining higher thermodynamic efficiency because the working fluid can achieve higher temperature in comparison to flat plate collector. Reflecting surface require less material and are structurally simpler than flat plate collector, which means cost per unit area of the solar collecting surface is therefore less than that of FPC.

However, concentrator system also has its own disadvantage these are; concentrator system collect little diffuse energy depending on the concentration ratio, tracking system is required and the reflecting surface require periodic cleaning and refurbishing [28].

2.3.2.2 Flat Plate Solar Collector (FPC).

Flat plate collectors are heat exchanger that transform solar energy to heat energy of the working fluid. Flat plate collectors are designed for application requiring energy delivery up to 100^0C above the environmental temperature. Flat plate collector collect both beam and diffuse solar radiation, do not require tracking of the sun and require little maintenance. They are mechanically simpler than concentrating collectors. Major application areas of collectors are solar water heating, building heating, air conditioning and industrial process heat [7].

2.3.2.2.1 Classification of Flat Plate Collector.

Flat pate collector can be classified in to different type

Based on the type of working fluid used

- Liquid based flat plate collector
- Air based flat plate collector (solar air heater)

2.3.2.2.2 Liquid Based Flat Plate Collector.

These types of collector are used to heat water or any other liquid. Water is most frequently used in liquid based system.

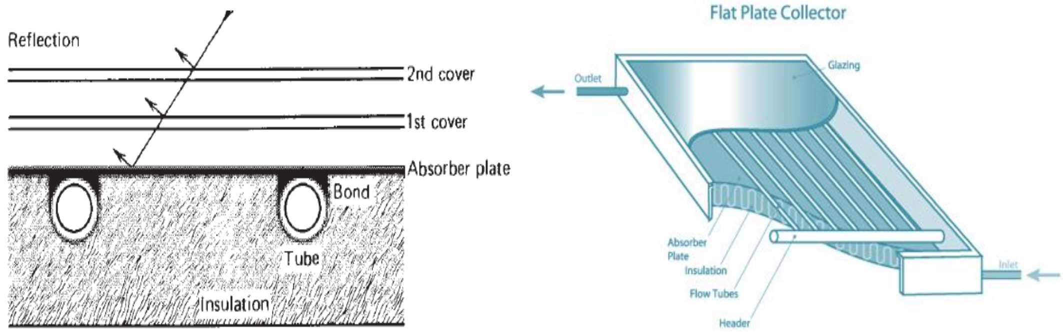


Figure 2.6. Double glazed flat plate solar water heater [7]

Typical flat plate water heating device shown on Figure 2.6. It consists of black solar energy absorbing surface with a means of transferring energy to the liquid, cover transparent to the solar radiation over the absorber surface to resist radiation and convection losses, tube for flow of liquid and back insulation to resist conduction and convection loss. Water based system is more efficient than that of air based system due to thermochemical properties of water and less leakage from the collector in comparison to air based system [7].

2.3.2.2.3 Flat Plate Solar Air Heater

Solar air heater has the same features to that of water (liquid based system), except the tube is replaced by air duct. Most solar air heater consists glass cover on top, insulation on sides and bottom to prevent heat loss to surrounding, a duct for air flowing and absorber plate. Air blowers or fan is also included in active systems to pressurize air from the environment to the air gap.

The thermal performance of solar air heater depends on several factors such as dimension of collector, absorber type and shape, glass cover inlet temperature and wind speed A.Beckman

[7].Both water based or air based system is used in solar heating and drying application based on the suitability of each for the purpose it is intended for.

Different types of configuration are suggested by different scholars for efficient operation of solar air heater. One of the issues which was considered by researchers to increase efficiency of heat transfer between the absorber plate and air Tarun.S [29].To increase heat transfer from the absorber plate to the flowing air, fin and v-corrugated absorber plate is used instead of flat plate absorber. Solar air heater with v-corrugated absorber plate can reach efficiency of more than 18% than that of flat plate absorber under the same operation condition Tao [30].

2.3.2.3 Solar Thermal Energy Storage.

Due to the problem of environmental degradation and depletion of conventional energy resource world is shifting its attention to renewable source of energy. As a result, the interest on solar energy increasing due its everywhere availability and environmental consideration [31]

Solar radiation is available for limited period of time a day. Most of the time energy is needed for time direct solar radiation is not available. Thermal storage system is a mechanism used to store thermal energy for the time solar radiation is not available.

Energy storage is not only plays an important role in conservation but also improves the performance and reliability of wide range of energy systems and become more important where energy source is intermittent such as solar. Energy storage process can reduce the rate of mismatch between energy supply and energy demand. The thermal energy storage can be used in places where there is variation in solar energy or in areas where there is high variation of temperature between day and night Mahmud M.Alkilani [32]

Water is used as energy storage medium in liquid based system and rock bed or phase change material (PCM) is used in air based system. However when water is compared with phase change material the volume required by water is higher than that of PCM [32].

The solar collection system determines the temperature at which the storage material will be charged at maximum rate of charge Goswami.D [28].Thermo physical properties of storage material is important in determining suitability of material for the process. Thermal energy storage materials divided into three main categories.

- Sensible heat storage material.
- Latent heat storage material.
- Thermo chemical heat storage system

2.3.3 Sensible Heat Storage

Sensible heat storage store thermal energy in solid or liquid medium. When the temperature of the medium rises it store energy due to its greater heat capacity. Water is one of the medium which is used as sensible heat storage medium. It has higher heat capacity. But its application is limited for application requiring thermal storage application below 100^0c thermal conductivity of such material is also low [33].

$$Q = \int_{T_1}^{T_2} mcdT \text{---} [2.1]$$

Low-temperature sensible heat storage mainly concerns solar water heaters for domestic hot water applications at the individual scale and district heating at large scale. Solar thermal systems are relatively complex, involving major draw-backs such as cost, storage tank location requirements and technical maintenance [34].

2.3.4 Latent Heat Storage

Latent heat storage is a storage mechanism that heat is absorbed or released when material changes its state [35]. The phase change that can be encountered should be solid to liquid, solid to solid or liquid to gas. Mainly most of phase change material used for latent heat storage involves phase transformation from solid to liquid phase change material (PCM) [35].

In latent heat storage heat is stored during melting and release heat during solidification of the phase change material. The input heat to the PCM changes its phase from solid to liquid by storing heat in the form of latent heat of fusion. When heat is recovered from the storage medium and it is released to the working fluid it changes its phase back to solid [34]. Paraffin wax is one of the best examples used as a phase change material for low temperature application. This is because of its desirable property such as chemical stability, non-corrosiveness and having higher latent heat [34].

$$Q=m\left[\int_{T_1}^{T_m} c_s dT + l + \int_{T_m}^{T_2} c_l \, dT\right] \text{------} [2.2]$$

2.3.5 Thermo Chemical Thermal Heat Storage

Thermochemical heat storage involves a sorption process, which involves capture of reactive gas by a condensed substance either by solid a process called adsorption or liquid by a process called absorption [35].

Solar air heater with thermal storage on of the methods used for increasing the efficiency of the heater. Storage system enhance the heater to be used for longer period of time. Different configuration of solar collectors are suggested by scholar for efficient operation. From those roof integrated solar heating system Figure 2.7 was discussed by saman [36].

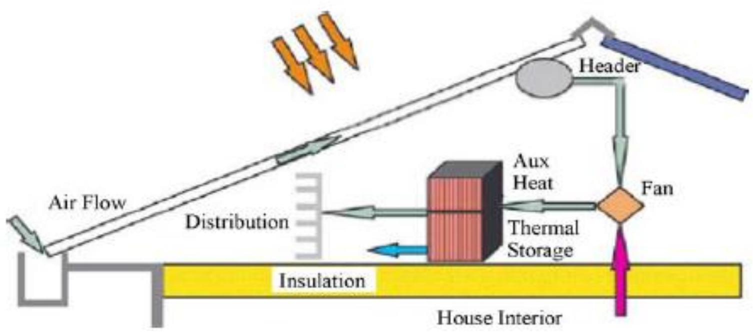


Figure 2.7. Roof integrated solar air heater with thermal storage system [36]

The unit consists of several PCM slab with melting point of 29^0c. Warm air is delivered by roof integrated collector passed through the layer between the roof and PCM to charge the storage unit. The stored heat is admitted to heat the ambient air before it is admitted to the room.

University of southern Australia developed new model of roof integrated solar air heating /storage system. Which uses existing corrugated iron roof sheets as a solar collector for heating air Goyal R.K [33] as shown Figure 2.8.

The system uses PCM to store energy during the day so that it can be used during the night time. During the day when there is solar radiation and heating is required air is pumped through the thermal collector, heated and then admitted to the room [32]. When heating is not required air is pumped through PCM so that it melts and store thermal energy.

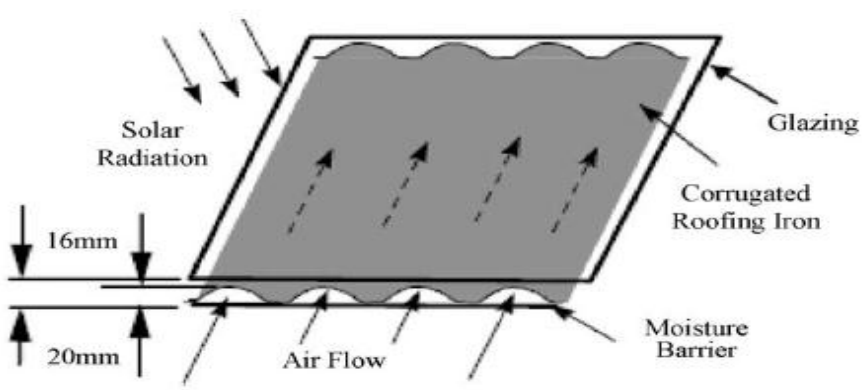


Figure 2.8. Roof integrated solar air heater [33]

The performance of the system generated 9% savings relative to a heat pump.

Tiwari .G.N [37] have experimentally evaluated crop dryer with water heater as storage material he reported energy balance equation and predicted analytical result, it is observed that the drying time is significantly reduced due to increase in thermal energy on the collector by the reflector. The system can be used to heat water in case when drying is not required. The water heater below the air heater system will act as a storage material for drying the crop during off –sunshine hour.

From his review solar air collector with thermal storage system with various storage materials and heat transfer studies on air as a heat transfer fluid. He conclude from this study that the recent researches focused on the phase change materials (PCMs) as a storage materials, because of the higher thermal energy storage density of these materials in contrast to sensible heat storage materials.

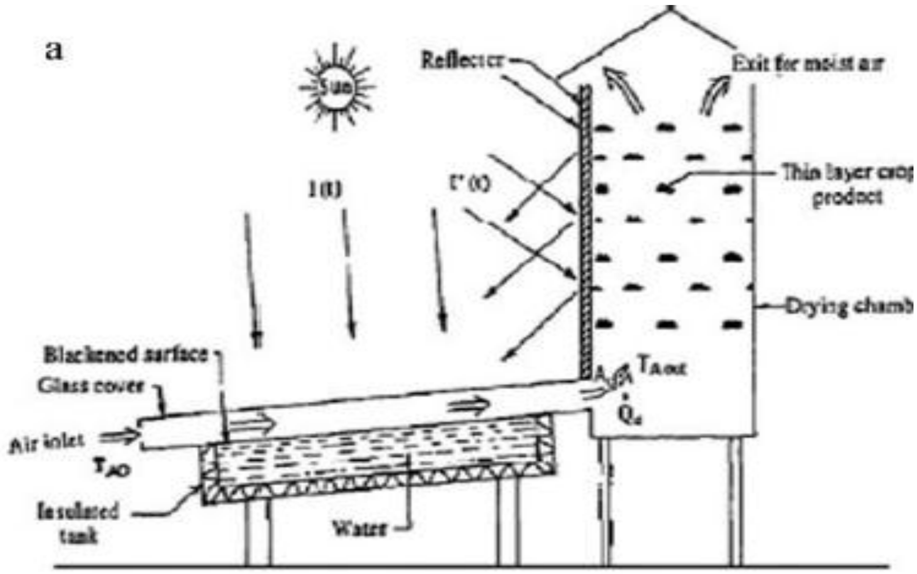


Figure 2.9. Solar crop dryer with thermal storage system [37]

2.3.6 Literature summary;

In general in this chapter previous works in poultry industry hatching method has been discussed. Many work has been done to improve efficiency of hatching and to increase production number. From the literature survey the following problem is identified as a gap for further work in this research. Electric incubators work with supply of grid provided electricity which make them limited in application [14] [8] [15]. Solar photovoltaic egg incubator was designed, constructed and tested by scholars. However, using photovoltaic panel for heating purpose result in higher cost of the incubator [6]. Passively heated solar poultry egg incubator that uses passive energy of the sun for heating of an incubator designed by scholars. Since it is exposed to direct sunlight it is subjected to higher temperature fluctuation.

The method used to control the temperature and other incubation parameter is manual method or by opening the ventilation hole when the temperature rise above the required level [18]. Solar micro base and solar thermal egg incubator introduce use of solar thermal energy for incubation purposes and thermal energy storage is used to store energy for the night time [17] [4]. However, the control of incubation parameters such as temperature, humidity and turning was done manually by opening and closing hot air duct between the collector and the incubation chamber. This requires continues attendance of the operator [17].

Hybrid electric and solar thermal avian egg incubator has higher energy saving potential but the design was done for large scale incubation or commercial incubation and it requires grid provided electricity for partial heating as well as control and monitoring of parameters during avian egg incubation process.

Hence the inapplicability of electric egg incubator in rural areas of the country, the importance of continuous attendance of the operator for control of incubation parameter of work done solar thermal egg incubator by Bolaji [17] and solar passive egg incubator by Ahiaba [18],the higher cost of the solar photovoltaic egg incubator [6] is identified as a gap in the research done in the past in this area (field of study).

This paper deals with the design construction and testing of solar egg incubator. The system consists of solar thermal energy collectors, low power photo voltaic panel, thermal storage system and incubator box. It uses solar thermal collector for heating and low power PV panel to drive accessories used for control of incubation condition such as ventilation fan and inlet fan for solar air heater. This system is selected since using photovoltaic panel for heating requires to arrange large arrays. This result in higher cost and unaffordable for poor farmer located in rural areas.

Using thermal system alone needs uninterrupted control of incubation factors by manual method. So the main work to be done in this paper is to design construct and test solar egg incubator by integrating flat plate thermal collector with latent heat thermal storage and low power photovoltaic panel to bring an alternative hatching method in village poultry industry of Ethiopia.

CHAPTER THREE

MATERIALS AND METHODS

In the review of literature that discussed in the previous chapter the available technology's in the poultry industry hatching method is studied their draw back and limitation are identified.

In this chapter the material and method analytical design of the machine for sizing the incubator box, the solar air heater or collector with thermal storage system based on the incubation load or the energy demand for incubation with the available solar radiation is discussed selection of auxiliary component for the control of incubation condition in the incubator box is also discussed.

3.1 Methodology

As mentioned above this research is concerned mainly to bring an alternative hatching method for rural areas which are far from grid provided electricity. In order to achieve the objective of the research the following methods and materials are used.

3.1.1 Data Collection

- Literature review –this part summarizes what has been done before, related to this study area and the gap is identified.
- Solar data's collection – solar data was gathered at specific location where the construction and testing is conducted. Although the machine is intended for use in rural areas of the country. Since manufacturing and testing is conducted in Addis Ababa solar data's were gathered from Ethiopian metrology agency for Addis Ababa.

3.1.2 Analytical Design

- This include estimation of available solar radiation and detail analytical design and sizing of the solar collector with thermal storage system as well as the incubator. In addition analytical modeling of heat collection mechanism in the collector, heat exchange between the collector and incubating chamber, the required size of the collector and thermal storage system based on the capacity of the incubator is decided.

- Paraffin wax is used for thermal storage system this is because it is nontoxic and available in market and moderate in cost where and it has the potential to store the heat energy required for incubation. Air is used as working fluid for heat exchange between the incubator and the flat plate collector.
- In addition to that selection of accessories is also included (parts that are used for control of the incubation parameter).

3.1.3 Geometric Modeling

- Geometric modeling of the collector and the incubator box is done using catia software. This include part and assembly drawings.

3.1.4 Prototype Construction and Testing of the Machine

- The prototype of incubation machine is constructed in a workshop from locally available material.
- **Testing of the machine-** after Construction of the machine is completed. Preliminary experimental test is conducted on the incubator to identify whether the system can supply the necessary temperature and humidity or not.

In addition test is conducted on the flat plate solar air heater to determine its efficiency. The thermal storage system is also tested for its capacity to discharge the required energy for the specified period of time that solar radiation is not available. The test is conducted and data's are recorded using **national instruments data logger with labview software.**

3.2 Conceptual Layout of the System

The layout of the system is shown on Figure 3.1. It is composed of the following sub section the solar collector with internally built thermal storage system, the incubator box and the support and control system.

The solar collector has parts such as glazing, absorber plate and the collector casing. Glazing is used to transmit the short wave radiation from the sun to the absorber plate and to prevent escape of the long wave radiation from the collector to the surrounding environment.

Absorber of flat plate collector is used to absorb energy and deliver it to the working fluid. The absorber plate is corrugated with angle iron to increase the heat transfer rate to the working fluid. The other advantage of corrugation is to increase the effective heat absorption area of the absorber plate. Thermal storage container is located under the absorber plate inside the casing of flat plate collector.

The other component of the solar egg incubator is the incubator box. It is a place where the egg to be incubated is kept. It has egg tray with tray support mechanism, turning mechanism and the water pan. Low power solar panel driven fan is used to pressurize air from the environment to the solar collector and for ventilation of the incubator box.

The working principle of the machine - air is pressurized from the environment to the air heater through the inlet fan and it is heated inside the air chamber of the collector due to heat transfer between the absorber and the air stream flowing through it.

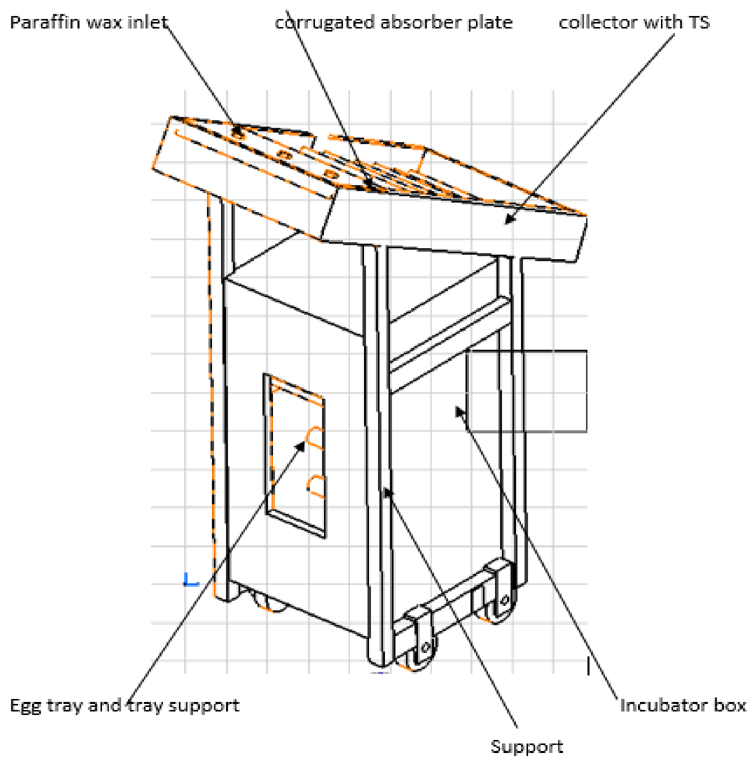


Figure 3.1. Conceptual Layout of the system

The heated air the flows through the hot air flow pipe due to the pressure difference created between the collector and the incubator box by the collector inlet fan, water pan is placed inside the incubator to humidify the incubator box. When the temperature of the incubator box rise above the recommended optimum temperature the ventilation fan is switched on and it charge the chamber with fresh and cold air reducing the temperature.

3.3 Incubation Total Energy Demand Assessment

Energy demand assessment (heating load) for incubation is calculated based on the desired incubation condition inside the incubator (incubation chamber) to obtain the required output at the final stage of incubation process. It is determined based on the optimum temperature the egg should be maintained to obtain the best possible result at the end of the incubation process.

During the incubation process thermal energy is needed to heat the eggs, to heat air inside the incubator box and to replace the lost energy from the system to the surrounding environment.

An incubator is a box that holds eggs while maintaining appropriate temperature, humidity, and oxygen level. The forced draft type egg incubator is discussed in this work, because of the temperature and humidity in a forced air incubator is more consistent. It also return to desired temperature and humidity more quickly after being opened [38]. Still air incubators can give inaccurate humidity and temperature readings and the temperature in it can vary considerably.

3.3.1 Heating Load during Incubation

In designing an incubator heat is required to raise the temperature of an egg and air inside the incubation chamber from initial storage temperature to optimum temperature of incubation. In addition to this some heat is also required to balance the heat lost from the chamber due to interaction that takes place with surrounding environment.

So the total heat requirement for incubation is the sum of heat required to raise temperature of air inside the incubator Q_a from room temperature to optimum temperature of incubation, heat required to raise temperature egg Q_e from the egg storage temperature to the optimum incubation temperature, heat lost through the wall of the incubator by conduction Q_c and heat lost by ventilation Q_v [17]

$Q_{tot} = Q_a + Q_e + Q_C + Q_v$ -- [3.1]

Where $Q_a = m_a c_a \Delta T$-- [3.2]

m_a= mass flow rate of air in the incubator

c_a= specific heat capacity of the air

$= 1.006$ KJ/Kg. K

ΔT=the temperature difference between environment and incubator.

The incubator box or the incubation chamber is a place where eggs to be hatched are placed and supplied with necessary condition. It has tray and tray support mechanism. It consists of four layers of egg tray each holding 20 egg. Figure 3.2 shows the schematic diagram of incubator box. Plastic egg tray of $[350\text{mm} \times 350\text{mm}]$ is used to hold the egg inside the egg chamber. The spacing between two trays is 0.15m.The total height of the incubator box is taken as 0.9m and the width and length is taken as 0.5m.

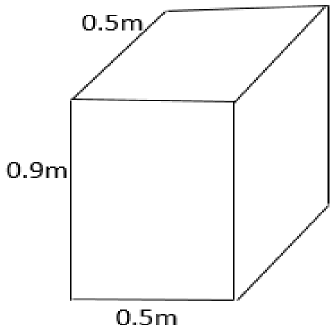


Figure 3.2. Schematic diagram of the incubator box

So the volume of incubator with size of $[0.5\text{m} \times 0.5\text{m} \times 0.9\text{m}]$

$$V_{inc} = (0.5\text{m} \times 0.5\text{m} \times 0.9\text{m}) = 0.225\text{m}^3$$

The standard atmospheric air temperature and pressure as well as air density is 100kpa, 15^0c and 1.22kg/m^3 at mean sea level respectively. Since Addis Ababa is located at an elevation of 2386m above sea level there should be variation in density due to the difference in temperature with the altitude and the weather condition. The average atmospheric temperature of the place is taken as 17.8^0c (data from national metrology agency of Ethiopia). Hence density of air at Addis Ababa can be calculated using the altitude and average air temperature the relation given by equation 3.3[52]

$$\rho_{a=\frac{353.049}{T}}e^{-0.034\frac{Z}{T}} \text{------------------------------------} [3.3]$$

$$\rho_{a=}\frac{353.049e^{-0.034\frac{2386m}{290.8k}}}{290.8k}$$

$$\rho_{a=0.913kg/m^3}$$

Considering air as a perfect ideal gas the pressure can be calculated using the relation given in equation 3.4 [39].

$$p = \rho RT \text{------------------------------------} [3.4]$$

Where p is pressure

ρ is density of air in =0.913kg/m^3

T is temperature in =290.8k

R is universal gas constant=0.287KJ/kg. k

$$P = \rho RT = \frac{0.913\text{kg}}{\text{m3}} \times \frac{0.287\text{KJ}}{\text{kg}}.\text{k} \times 290.8\text{k} = 76.2Kpa$$

Hence the average atmospheric pressure is taken as 76.2Kpa.

From the literature summary the optimum temperature and relative humidity for incubation of chicken egg is 37.8^0c and 60% respectively [13]. Hence the incubator box should be maintained at the recommended value for the best result at the end of the incubation process. However the density varies with the variation of temperature and relative humidity. Hence its Value is calculated at the given condition. Assuming that the incubator box is at atmospheric pressure of the location of the place, Density of air at temperature of 37.8^0C and relative humidity of 60% is calculated by using humid air density using thermodynamic relations.

The total pressure of the air is the sum of partial pressure of water vapor and the dry air [39]

$$P = Pa + Pv \text{-- [3.5]}$$

$P_v = \emptyset P_{sat@T}$ From the saturated water table $P_{sat@37.8^0c} = 6.6125kpa$

$$P_v = 0.6 \times 6.6125kpa = 3.9674kpa$$

Assuming the incubator box at the same pressure with environment in order to avoid uncontrolled flow of air due to pressure gradient. Then the humidity ratio of the humid air inside the incubator box can be calculated using the relation given below [39].

$$\omega = 0.622\frac{P_v}{P-P_v} \text{--- [3.6]}$$

$$= 0.622\,\frac{3.967kpa}{76.2Kpa-3.967kpa}$$

=0.03413

The specific volume is calculated using the relation given by

$$v = 287\frac{273+T}{P-P_v} = 1.2 \text{-- [3.7]}$$

Hence the density of air at specified temperature and relative humidity can be determined using the relation

$$\text{density } \rho = \frac{1+\text{hummidity ratio}}{\text{specific volume}} \qquad [3.8]$$

$$= \frac{1+0.0342}{1.2} = 0.86\text{kg}/m^3$$

To calculate the total heat load inside the incubator according to metrological data obtained from Ethiopian meteorology agency average atmospheric temperature of the environment for Addis Ababa is taken as 17.7^{0}C. The mixture of air and water vapor can be considered as an ideal gas in air conditioning application [39].

The optimum temperature for incubation for chicken egg is 37.8^{0}C [13].To calculate the mass flow rate of the air inside the incubator, The volume flow rate of air inside the incubator can be calculated by equation of continuity between the hot air pipe and the incubating chamber shown Figure 3.3

Since air flow from the solar collector to the incubation chamber due to the pressure difference between them created by the inlet fan it is assumed that diameter of hot air pipe is 40mm

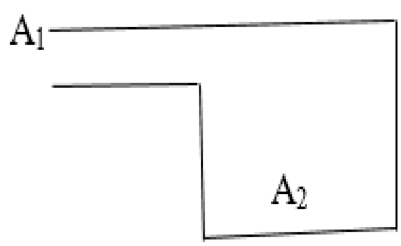


Figure 3.3 Areas of connection of air flow pipe and incubator box

The area of hot air pipe is calculated by using the following formula

$$A_1 = \frac{\pi}{4} d^2$$

$$= \frac{\pi}{4}(40\text{mm})^2$$

$$= 0.0013\text{m}^2$$

The speed of flow of air inside the hot air chamber is obtained from the mass flow rate of the fan. From the fan used speed of air flow is 2.5m/s from the volume flow rate of the fan.

The area of the incubating chamber is A_2 with a size of $[0.5m \times 0.5m]$

$$A_2 = 0.5m \times 0.5m$$

$$= 0.25m^2$$

Then from the equation of continuity

$$A_1 v_1 = A_2 v_2$$

$$0.0013m^2 \times 2.5m/s = 0.25m_2 \times v_2$$

$$V_2 = 0.013m/s$$

Mass flow rate $m_a = 0.013m/s \times 0.86kg/m^3 \times 0.25m^2$

$$= 0.00279kg/s$$

$$Qa = m_a \, c_a \, \Delta T \text{ -- [3.9]}$$

$$= m_a \, c_a \, (T_{inc} - T_{env})$$

$$= 0.00279kg/s \times 1.006 \, kJ/kg.k \times (310.8k - 290.7k)$$

$$= 56.5w$$

The heat required to raise the temperature of egg from initial temperature to optimum temperature of the incubator assuming that the egg is preheated to 24^0c before it is placed inside the incubator for the process of incubation.

In order to avoid over heating of the egg this heat is supplied gradually to the incubator with the recommended heating rate. Eggs that are transferred directly from storage to the incubator is heated at rate of 0.30 ^0c/min whereas egg that are preheated or transferred from the pre heater to the incubator are warmed at rate of 0.13^0c to 0.16^0c/min [41]. Since it is assumed that the egg is preheated considering it is heated at a rate of 0.16^0c.

$$Qe = m_e \, c_e \, \Delta T \text{ -- [3.10]}$$

Where

M_e=average mass of the egg

$= 0.068kg$ [40]

C_e= specific heat capacity of egg

$= 3.18kJ/kg.^0c$

For single egg

$$Qe = m_e \, c_e \, \Delta T$$

$= 0.068\text{kg} \times 3.18\text{KJ/kg.}^0\text{c} \times 13.8^0\text{c}$

$= 2.98\text{kJ /egg}$

The total energy required for incubation of 80 egg

=number of egg × the total heat required for single egg.

$$\text{Qe} = 2.98\frac{\text{KJ}}{\text{egg}} \times 80\text{egg} = 238.7\text{KJ}$$

This amount of heat is needed to raise the temperature of egg from initial temperature to the optimum temperature of incubation and to keep it there.

Time required to raise the temperature of the egg inside the incubator from room temperature to the optimum temperature of incubation is

$$T=\frac{\text{temprature difference}}{\text{warming rate}} \quad [3.11]$$

$$=\frac{13.8}{0.16\text{c/min}}$$

$$= 5175\text{s}$$

So the amount or quantity of heat supplied to the incubator per second is given by

$$Q_e=\frac{\text{total amount of heat supplied}}{\text{time required to raise the temprature of egg}} \quad [3.12]$$

$$=\frac{238\text{KJ}}{5175\text{s}}$$

$$= 46\text{w} = 50\text{w}$$

Heat loss by conduction Q_c

These account for heat lost from the incubator box surface by conduction. The incubator box with [0.9m × 0.5m × 0.5m] dimension.

Heat loss by conduction

$$Q_c = KA\frac{\Delta T}{\Delta X} \quad [3.13]$$

Where

K is the thermal conductivity of material of incubator plywood.

A is total surface area of the incubator

ΔT is the difference in temperature between incubator and environment

Δx is the thickness of plywood

$$K = 0.045\text{w/m}^2\text{.k} \ [42]$$

$\Delta T = 20k$

$\Delta x = 30mm$

A=total surface area of incubator box

The incubator box consists of 4(four) $0.5m \times 0.9m$ rectangular plate and 2(two) $0.5m \times 0.5m$ plate so total surface area of the plate is given by

$$A = 4 \times (0.5 \times 0.9) + 2 \times (0.5 \times 0.5)$$

$$= 2.3m^2$$

The total heat lost by conduction

$$Q_c = KA\frac{\Delta T}{\Delta X}$$

$$= 0.045\frac{w}{m^2.k} \times 2.3m^2 \times \frac{20k}{0.03m}$$

$$= 69w$$

The heat lost by ventilation is given by

$Q_v = \rho_{air} \times v \times C_p \Delta T$ -- [3.14]

V is volume flow rate or rate of ventilation

$\Delta T = 20k$

Ventilation is required to control the rise of temperature it is not continues process the volume flow rate of mini fan used for ventilation Volume flow rate of ventilation air in pipe= $0.00041m^3/s$ from the fan used for the ventilation purpose.

$Q_v = \rho_{air} \times v \times C_p \Delta T$--- [3.15]

$$= 0.913\ kg/m^3 \times 0.00041m^3/s \times 1.006kJ/kg.k \times 20k$$

$$= 7.5w$$

The total heat needed for incubation is equal to the sum of all heat required to raise the temperature of egg from the room temperature to the incubation temperature, heat lost by ventilation, hence from equation 3.1

$$Q_{tot} = Q_a + Q_e + Q_c + Q_v$$

$$= 56.2w + 50w + 69 + 7.5w$$

=182.7w=185w

Hence the solar collector should have to supply 185w of thermal energy during the incubation process.

3.4 Design of Flat Plate Collector and Thermal Storage System

3.4.1 Flat Plate Design

Flat plate collector is one of the most common types of solar collector design. It is designed for application requiring moderate temperature, up to 100^0C [7]. Of this type of collector can be designed and constructed from different material based on the type of environmental condition in which the collector is used.

The system basically is a box that has a glass or plastic cover on the top and absorber plate on the bottom. Different material can be used for the absorber plate. Material such as copper, aluminum and steel most frequently used as an absorber. Insulation are used at the back of the box to minimize heat losses.

Sectional view of flat plate collector with thermal storage system is shown in Figure 3.4 the storage is located under the absorber plate.

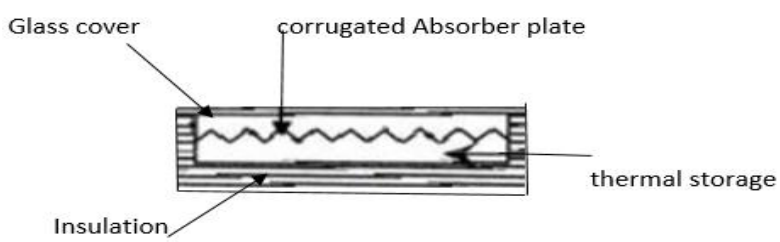


Figure 3.4. Sectional view of flat plate collector with thermal storage system

In this type of configuration absorber is used for both absorbing solar radiation and exchanging heat to the thermal storage media during charging and discharging period.

3.4.2 Estimation of Solar Radiation

The estimation of the amount of solar radiation available in any selected area is a primary task before starting design and sizing a system that require solar energy. To do this estimation the geometric relationship between any planes of particular orientation and the position of the sun in the sky is one of the most important factor that has to be considered. The following angles are used to describe the geometric relationship between any plane and the sun.

The design is for Addis Ababa located

a) Latitude=8.98^{0}N

ϕ=9^{0}N

b) Longitude =38.7^{0}E

c) Elevation=2386m above sea level

3.4.2.1 Declination ($\boldsymbol{\delta}$)

Declination the angular position of the sun at solar noon with the plane of equator, north positive (-23.45^0$\leq \delta \leq 23.45^0$) [7].

Declination $\delta = 23.5 \sin\left[\frac{360}{365}(284 + \mathrm{N})\right]$-- [3.16]

Where N is the day of month and angels are measured in degrees. The day for the design of flat plate solar collector selected is October with representative day of 15 so N=288

Declination δ = 23.47sin $\left[\frac{360}{365}(284 + 288)\right]$

=-9.6^0

Table 3.1 Declination and earth sun distance for the representative average days of the month

i^{th} day of the month	Month	N for i^{th} the day of the month	Julian day of the year n	Declination δ In degrees	Earth -sun Distance E_o in AU
17	January	i	17	-20.92	1.03
16	February	31+i	47	-12.95	1.02
16	March	59+i	75	-2.42	1.01
15	April	90+i	105	9.41	0.99
15	May	120+i	135	18.79	0.98
11	June	151+i	162	23.09	0.97
17	July	181+i	198	21.18	0.97
16	August	212+i	228	13.45	0.98
15	September	243+i	258	2.22	0.99
15	October	273+i	288	-9.60	1.01
14	November	304+i	318	-18.91	1.02
10	December	334+i	344	-23.05	1.03

Source; Solar Engineering Thermal Process, Duffie and Beckman [7]

3.4.2.2 Hour Angle (ω)

Average Sun shine hour or solar time for is obtained from meteorological data for Addis Ababa is 6.6 hours [7]

$$\omega = (ST - 12) \times 150 \text{ ---} [3.17]$$

$$= (14{:}30 - 12)15^0$$

$$= 34.5^0$$

$$= 34.5^0 \text{ after noon}$$

3.4.2.3 Determination of Tilt Angle

At weather stations solar data's or global solar radiation is measured on horizontal surface. Nevertheless to take advantage of solar radiation on surface of a collector conventional stationary solar system, both photovoltaic and flat pate solar collector are mounted on an inclined surface [43]. Moreover, since the amount of solar radiation incident on a solar thermal collector or a photovoltaic panel is strongly affected by its installation angle and orientation finding the optimum tilt angle to receive maximum solar radiation on a photovoltaic or flat plate thermal panel is the cheapest and most effective method [43].

The optimum tilt angle for maximum energy utilization of flat plate solar collector located in tropical regions is

$$\beta=\varphi\pm 15 \text{ --} [3.18] [44]$$

It is $\beta = \varphi + 15$ for winter and $\beta = \varphi - 15$ for summer

So the optimum tilt angle for flat plate solar collector located in Addis Ababa with latitude $\varphi=9^0$

$$\beta = \varphi + 15^0$$

$$= 9^0 + 15^0$$

$$= 24^0$$

To calculate the solar altitude angle. The flat plate collector is oriented at an angle 24^0 inclined toward south direction

Zenith angle θ_z; it is the angle of the sun relative to a line perpendicular to the earth's surface [28]

Zenith angle (θ_z) is given by equation 3.13 for flat plate collector oriented horizontally it is equal with angle of incidence

$$\cos\theta z = \sin 9 \sin\delta + \cos\delta \cos\phi \cos\omega \text{-----} [3.19]$$

For a collector oriented with certain amount of tilt angle it is the sum of the tilt angle and angle of incidence of the sun.

$$= \sin(9)\sin(-9.6) + \cos(-9.6)\cos(9)\cos(34.5)$$

$$= 0.156 \times -0.164 + 0.986 \times 0.987 \times 0.824$$

$$\theta_z = 39.1^0$$

The solar azimuth angle is calculated using the equation given below [7]

$$\theta_z + a_s = 90^0 \text{-----} [3.20]$$

$$56.2 + a_s = 90^0$$

$$a_s = 90^0 - 39.1^0$$

$$= 50.9^0$$

3.4.2.4 Angle of Incidence

The angle of incidence for a surface tilted at an angle β from the horizontal can be calculated by using the formula since Addis Ababa is located in northern hemisphere [7]

$$\cos\theta = \cos(\varphi - \beta)\cos\delta\cos\omega + \sin(\varphi - \beta)\sin\delta \text{-----} [3.21]$$

$$\cos\theta = \cos(9 - 24)\cos - 9.6\cos 34.5 + \sin(9 - 24)\sin - 9.6$$

$$\theta = 34.1^0$$

The sun shine hour angle can be calculated by the following relation [7]

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \text{-----} [3.22]$$

$$= \cos - 1(-\tan 9\tan - 9.6)$$

$$= 88.7^0$$

3.4.2.5 Average Hourly Radiation

To determine global solar radiation on an inclined surface average hourly radiation on horizontal surface for the month October is taken from metrological data for Addis Ababa 602.5w/m^2 (from national metrology agency)

3.4.2.6 The Hourly Exterristorial Radiation

The average hourly exterristorial radiation for representative day of April N=288 can be calculated using

$$I_O = I_{sc}\left(1 + 0.033\cos\frac{360N}{365}\right)\cos\theta_z \text{------} [3.23]$$

$$= 1337\frac{w}{m^2}\left(1 + 0.033\cos\frac{360 \times 288}{365}\right)\cos 39.1^0$$

$$= 1037.5\frac{w}{m^2}$$

3.4.2.7 Clearance Index

This most important radiation parameter K_T is principally measure of the radiation that is transmitted through the atmosphere and is therefore dependent only on the extraterrestrial radiation and the radiation falling at the earth's surface. [7] The hourly clearness index K_T during particular hour is the ratio of hourly global radiation on the horizontal surface to the hourly extraterrestrial radiation on the horizontal surface during the same time period [7]

$$K_T = \frac{I}{I_O} \text{------} [3.24]$$

And monthly average hourly clearness index [7]

$$\bar{K}_T = \left[\frac{\bar{I}}{\bar{I}_o}\right] \text{------} [3.25]$$

Using equation 3.2

$$K_T = \frac{I}{I_O}$$

$$= \frac{602.5}{1037.5}$$

$$= 0.58$$

3.4.2.8 Determination of Hourly Diffuse Radiation from Hourly Global Radiation

To predict hourly diffuse radiation on horizontal surface using the following correlation

$$\frac{I_d}{I} = \begin{cases} 1 - 0.249K_T & \text{for} \quad (0 \le K_T \le 0.35) \\ 1.557 - 1.84K_T & \text{for} \quad (0.35 \le K_T \le 0.75) \\ 0.177 & \text{for} \quad K_T > 0.755 \end{cases} \text{------}$$

[3.26]

From equation 3.29 for clearance index $K_T = 0.58$

$$\frac{I_d}{I} = 1.557 - 1.84K_T$$

$$= 1.557 - 1.84(0.58)$$

$$=0.48$$

$$I_d = 0.48 \times 602.5 \frac{w}{m^2}$$

$$=289.2\frac{w}{m^2}$$

Hourly total radiation on horizontal surface can be

$$I = I_b + I_d \text{--} [3.27]$$

$$I_b = 602.5 \frac{w}{m^2} - 289.2 \frac{w}{m^2}$$

$$I_b = 313.5 \frac{w}{m^2}$$

3.4.3 Conversion factors

Result obtained from the above calculation is for collectors oriented horizontally. So conversion factors are used to convert result obtained on horizontally oriented plane to a plane oriented over inclined plane (to a plane oriented at certain tilt angle). Conversion factors for beam, diffuse and reflected radiation are given as follows A.Beckman [7]

Beam radiation conversion factor is the ratio of cosine of incidence angle to the cosine zenith angle [7]

$$R_b=\frac{\cos\theta_i}{\cos\theta_z} \text{--} [3.28]$$

$$=\frac{\cos 34.1}{\cos 39.5}$$

$$=1.06$$

Diffuse radiation conversion factor [7]

$$R_d=\frac{1+\cos\beta}{2} \text{---} [3.29]$$

$$= \frac{1+\cos 24}{2}$$

$$=0.96$$

Reflected radiation conversion factor is given by

$$R_r = \frac{1-\cos\beta}{2} \text{---} [3.30]$$

$= \frac{1-\cos 15}{2}$

$= 0.043$

3.4.3.1 Total Hourly Radiation on Inclined Surface

The total amount of hourly radiation on the inclined plane is the sum of diffuse beam and reflected radiation

ρ=is taken as 0.22 for reflected radiation from the ground only [28]

$I_T = R_b \; I_b + R_d \; I_d + \; R_r\rho(I_b + I_d)$ -- [3.31]

$= 1.06 \times 313.5 w/m2 + 0.96 \times 289.2 w/m2 + 0.22 \times 0.045 \times 602.5 w/m^2)$

$= 615.6 w/m^2$

3.5 Energy Gained by the Collector

To determine the total energy gain, temperature distribution and efficiency of the flat plate collector the following assumption should be stated first to simplify the analysis in the process of sizing the collector.

Assumption

1. The system operate under steady state condition
2. There is no absorption of solar energy by a cover in so far as it affects losses from the collector.
3. There is negligible temperature drop through the cover or glazing
4. The covers are opaque to infrared radiation
5. The sky can be considered as a black body for long wave radiation at equivalent sky temperature.
6. The air temperature change only in the flow direction of air or air stream or temperature gradient in direction perpendicular to the flow of air is negligible
7. The heat transfer through glass cover and absorber plate is 1-D and in the direction of perpendicular to the direction of air flow.

The total energy gained by the collector (the useful energy gain) can be determined by using the following equation [30]

$Q_u = A_c\,(S - U_l(T_c - T_a))$-- [3.32]

S =absorbed solar radiation

A_c = area of collector

U_l=overall heat loss from the collector

T_c= collector temperature

T_a =ambient temperature

If the heated air leaving the collector is at the collector temperature then the useful energy gain by the air which is expressed as Q_g [7]

$Q_g = m_a C_{pa}(T_c - T_a)$-- [3.33]

$M_{a=}$mass of air leaving the collector per unit time (Kg/s)

C_{pa}= specific heat capacity of air (Kj /Kg. K)

3.6 Thermal Efficiency of V-Grooved Collector

The efficiency of thermal collector useful energy gain to the incident solar energy [32]

$\text{Efficiency of collector} = \frac{\text{usefull energy gain}}{\text{total incident radiation}}$

$\eta = \frac{Q_u}{AI_T}$---

[3.34]

For v grooved collector taking iron cover as an absorber plate the following dimensions are obtained from measurement mean height $H_g = 23\text{mm}$,breadth $= 40$ and the inclined length of the is $= 30\text{mm}$

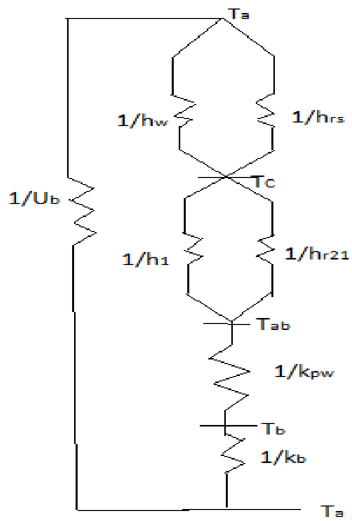


Figure 3.5 Thermal network of flat plate collector with thermal storage system

For design and analysis of flat plate solar collector the flowing average parameters are taken The ambient temperature from metrological data average atmospheric temperature for Addis Ababa $= 290.7k$

- Air gap spacing from the flat surface to the glass cover $H = 40mm$
- Mean absorber plate temperature $T_{pm} = 313k$
- Absorber plate emittance, $\varepsilon_p = 0.9$ [45]
- Absorber absorpitance $\alpha = 0.956$ [45]
- Glass cover emittance ε=0.84 [45]
- Mean glass cover temperature T=303k
- From property table of air K=0.0278w/m .k [45]

3.6.1 Overall Heat Loss Coefficient Calculation for V-Grooved Flat Plate Collector

For forced convection v-corrugated flat plate collector the convection heat transfer coefficient between the glass cover and the absorbing plate.

$$h_1 = Nu_{ap-c}\frac{k}{Hc} \text{------------------------------------} [3.35]$$

H_c Is mean gap thickness between the cover and absorbing plate hence it is calculated by

$$H_c = H + 0.5H_g \text{------------------------------------} [3.36]$$

=17+0.5(23)

=30mm [46]

H=17mm

Where H_g is the height of the v- grooved absorber [46]

When $Re < 2800$

$$Nu_{ap-c} = 2.821 + 0.126Re\frac{Hg}{L} \quad \text{[3.37]}$$

$2800 \leq Re \leq 10^4$

$$Nu_{ap-f} = 1.9 * 10^{-6}Re^{1.79} + 225\frac{Hg}{L} \quad \text{[3.38]}$$

$10^4 \leq Re \leq 10^5$

$$Nu_{ap-f} = 0.0302Re0.74 + 0.242Re0.74\frac{Hg}{L} \quad \text{[3.39]}$$

Reynolds number for v- grooved flat plate collector

$$Re=\frac{DpUfh}{\mu} \quad \text{[3.40]}$$

Hydraulic diameter of v grooved flat pate collector

$$D_h=\frac{2}{3}H_g \quad \text{[3.41]}$$

$= \frac{2}{3}23mm$

$= 15.3mm$

U_f=is speed of flowing air between the v-grooved absorber plate and glass cover

Assuming the air speed

$U_f = 2.5m/s$

Dynamic viscosity of air $\mu = 1.963 * 10^{-5}kgm - s$

$$Re=\frac{DpUfh}{\mu} \quad \text{[3.42]}$$

$$= \frac{0.0153m\times\frac{2m}{s}}{1.963\times10-5kgm-s} = 1558.8$$

Since the Reynolds number is less than 2800

When $Re < 2800$

$$Nu_{ap-c}=2.821 + 0.126Re\frac{Hg}{L} \quad \text{[3.43]}$$

$= 2.821 + 0.126\frac{23mm}{500mm} \times 1558.8$

$= 11.85$

Hence $h_1 = Nu_{ap-c}\frac{k}{Hc}$-- [3.44]

$=11.85\,\frac{0.0278w/mk}{0.04m}$

$= 10.96w/k$

Radiation heat transfer coefficients between the glass cover and the absorbing plate

$$h_{r21} = \frac{\delta(T_{ap}{}^2+T_c{}^2)(T_{ap}+T_c)}{\frac{1}{\varepsilon_{ap}}+\frac{1}{\varepsilon_c}-1}$$ -- [3.45]

$\alpha = 5.669 \times 10^{-8}$

$$h = \frac{5.669\times10^{-8}(313^2+303^2)(313+303)}{\frac{1}{0.9}+\frac{1}{0.84}-1} \quad = 5.09w/k$$

The overall top loss coefficient is

$U_t = h_w + h_{rs}$--- [3.46]

The convection heat transfer coefficient from the glass cover due to wind is

$h_w = 5.7 + 3.8v_w$--- [3.47]

Taking average wind speed for Addis Ababa for the month October from Addis Ababa weather station $v_w = 0.63m/s$

$h_w = 5.7 + 3.8 \times 0.63m/s$

$= 8.1$

Radiation heat transfer coefficient from the glass cover to sky referred to the ambient air Temperature T_a can be obtained by equation [46]

$$h_{rs} = \sigma\varepsilon_c[T_c + T_s][T_c{}^2 + T_s{}^2]\left[\frac{T_c+T_s}{T_c-T_s}\right]$$ -- (3.48)

Assuming the temperature of the sky is equal with the surrounding environment temperature

$T_s = T_a = 17.8^0c$

$$h_{rs} = \sigma\varepsilon_c[T_c + T_s][T_c{}^2 + T_s{}^2]\left[\frac{T_c+T_s}{T_c-T_s}\right]$$

$h_{rs} = 5.669 \times 10^{-8} \times 0.84[303k + 290.7][303k^2 + 290.7k^2]$

$= 4.984w/k$

$$U_t = \left[\frac{1}{h_{21}+h_1} + \frac{1}{h_w+h_{rs}}\right]^{-1}$$ -- [3.50]

$$U_t = \left[\frac{1}{\frac{10.98w}{k}+\frac{5.09w}{k}} + \frac{1}{\frac{8.1w}{k}+\frac{4.9w}{k}}\right]^{-1}$$

$= \quad 7.18 w/m^2 k$

Heat loss from the thermal storage material or paraffin wax is only by conduction heat transfer

U_c Is conduction heat loss coefficient of paraffin wax?

$U_{pcm} = \frac{y}{K_{pw}}$ -- [3.51]

Where y is the thickness of paraffin wax it is taken as 5cm=50mm

K_{pw} is the thermal conductivity of paraffin wax =0.24w/mk [47]

$$U_{pcm} = \frac{0.05m}{\frac{0.24w}{mk}}$$

$$= 0.208 w/m^2 k$$

Heat loss through the back insulation is loss by conduction and radiation. Since the radiation heat loss is very small through the back insulation it is neglected and the only type of loss from the back insulation is conduction heat loss

The bottom side of the incubator is insulated from the bottom side by plywood with thermal Conductivity of $K_b = 0.045 w/m.k$ and insulation thickness of 30mm

$U_b = \frac{\text{insulation thickness}}{\text{thermal conductivity of insulation materail}}$-- [3.53]

$= \frac{t_{insulation}}{K_b.A}$

$= \frac{0.03m}{\frac{0.045w}{m}.k}$

$= 0\ .6 w/m^2 k$

Conductance of plywood is taken as 0.04w/ m k [42]

$$T = 30mm$$

Therefore the total heat loss coefficient U_l which is the sum of all loss coefficients from the collector.

$U_l = U_t + U_b + U_{pcm}$-- [3.55]

$= 7.18 w/m^2 k + 0.6/w^2 k + 0.2 w/m^2 k$

$= 7.98 w/m^2 k$ = 8w/$\mathbf{m^2\, k}$ is taken

Q_u Useful energy output of a collector which is defined as the difference between the absorbed solar radiation and the thermal loss.

$$Q_U = A_c\,(S - U_l\,(T_{pm} - T_a)\text{-- [3.56}$$

Where A_c area of the collector in the above equation the first term represents the absorbed solar radiation and second term represents the heat loss from the collector. The thermal energy loss from the collector to the surrounding can be represented as the product of heat loss coefficient U_L times the difference between the mean absorber plate temperature T_{pm} and the ambient temperature T_a.

Average hourly absorbed solar radiation per unit area of absorber can be calculated from the average daily total radiation on the inclined surface and the product of absorpitance and transmittance.

The transmittance of absorber plate with an angle of incidence

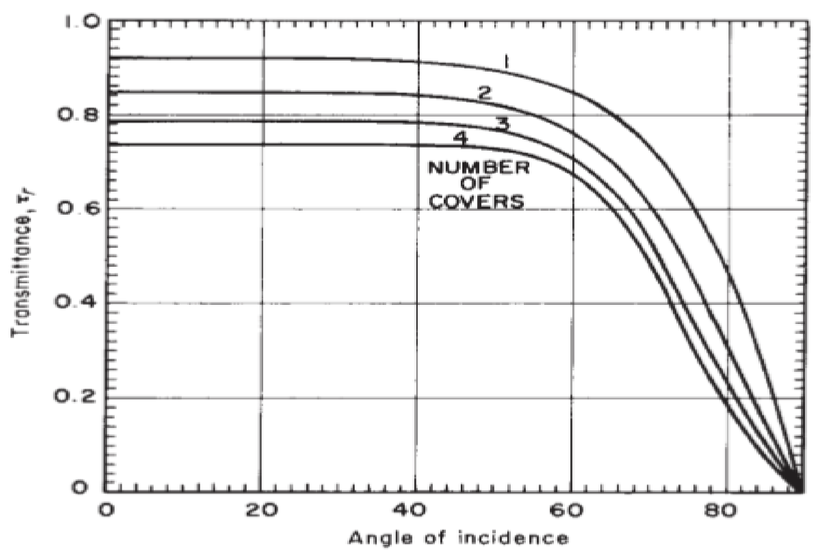


Figure 3.6 Transmittance of one two three and four cover three types of glass [7]

Transmittance for an absorber with angle of incidence 34.1^0 =0.92

$$s = (\tau\sigma)I_T\text{-- [57]}$$

$$= (0.92 \times 0.96) \times \frac{615\text{w}}{\text{m}^2} = 543.2\text{w/m}^2$$

For sizing the collector or to find the area of collector the total energy demand or load of the incubator calculated in the load analysis is equal with useful energy gain of the collector. That means the collector should have to supply the amount of energy needed by the incubator for the incubation of the given amount of egg including the lost heat energy.

From the useful energy gain of a collector

$$Q_u = A_c(s - U_l(T_{ap} - T_a)$$

$$Q_u = 200w$$

$$T_{ap} = 313k$$

$$T_a = 290.7k$$

$$U_l = 8w/m^2k$$

For well insulated system the edge loss is neglected. Hence from above equation we have

$$185w = A_c(\frac{543.2w}{m^2} - \frac{8w}{m^2k}(313k - 290.7k))$$

$$A_c=0.5m^2$$

An area $0.5m^2$ can absorb the required amount of solar radiation for heating the incubator. This should be the effective area of the surface of the absorber. The absorber for the case this design is v-corrugated. One of the advantage of corrugated absorber to increase surface area for heat transfer to the air stream flowing over it and increasing solar radiation absorbing area. The total area of corrugated absorber is $0.6m^2$.

3.7 Design and Sizing of Thermal Storage System

Solar energy is available everywhere but due to intermittency in its nature, to satisfy energy demand storage system is required. Storage system is mechanism which is used to store solar energy for use during off-sunshine hour (sunset hour). Therefore; energy storage systems must be associated with solar energy capturing to cover energy needs while direct solar radiation is not available. It can be stored in the form of electricity using battery storage in solar PV system, in the form potential energy storage in solar water pumping and in the form of thermal energy in solar thermal system.

Thermal energy storage is method used to accumulate low temperature or high temperature for later time utilization. It is needed when there is mismatch between production and energy demand. Thermal energy is stored when there is over production of energy and it is used during the time when there is shortage or complete absence of the production. Different techniques are used for thermal energy storage. The most widely used is the sensible heat storage method. Other techniques such as latent energy storage and thermochemical energy storage are appearing offering great heat storage capacity and reduced heat loss during the storage period.

Latent heat storage involves the heat absorbed or released when a material changes from one physical state to another (when it is subjected to a phase change).Different phase change can be encountered in PCM. Solid-solid, solid-liquid, solid-gas and liquid-gas in paraffin wax is used as a thermal storage material.

3.7.1 Selection of Thermal Storage Material

While designing the thermal storage system considering the needed property for the application it is required is important. High thermal storage capacity, good transfer rate between the thermal storage system and the working or heat transfer fluid, chemical alertness to avoid chemical and mechanical degradation of container are the desirable factor for thermal storage system [31]. In addition to the above listed property while selecting PCM material for thermal energy storage. Information related to storage material density, specific heat capacity and latent heat or energy density is needed. High heat capacity is required since it allow the material to store more sensible phase. High density needed to minimize the volume of thermal storage container. High latent heat is required to provide higher thermal energy per unit weight of the storage material [47]

In general as discussed in the literature thermal storage material are divided in to three general groups' Latent heat storage material, Sensible heat storage material and thermochemical storage material. Latent heat storage system is preferable over the sensible and thermochemical heat storage system due to its occupancy of small volume container and higher energy density and availability with varying melting point [48].

Latent heat storage material is a material that store thermal energy when it undergo phase transformation. The most common phase transformation is solid-liquid and vice versal. Different type of material are categorized under the phase change material (PCM).

The following are the required properties of PCM material

Thermo physical Properties

- The melting point or the phase change temperature of the storage material should be in appropriate range with the application it is required for.
- Higher latent heat sensible heat is desired per unit volume of the storage material.
- Larger thermal conductivity in both liquid and solid phase.
- The expansion rate during phase change should be small.
- No component segregation in solid phase.
- High nucleation rate
- High crystal growth rate
- For fast charging and discharging rate.

Chemical properties

- Completely reversible during charging and discharging phase.
- Less chemical degradation with time with the charging and discharging cycle.
- Non-corrosive
- Non-toxic, non-flammable and non-explosive.

In addition to the above listed thermo physical and chemical properties the PCM material must be available, low in cost and recyclable and environmentally non-pollutant. [48]

PCM is divided as organic PCM, inorganic PCM and metallic PCM.

3.7.2 Organic PCM

These are among the most commonly applied PCM. These include alkane such as paraffin wax and fatty acids families of fatty acids. Organic PCM are preferable for medium temperature application. Fatty acids have lower melting point and preferable for thermal comfort for building and houses. Organic PCM physically and chemically stable cheap and available. However their low thermal conductivity limit their applicability.

3.7.3 Inorganic PCM

The first type PCM used for thermal energy storage is inorganic PCM. Water ice is used for cold storage. To lower the melting temperature of water salts are added. Common inorganic PCM are salt and salt hydrates. Salt hydrates are combination of inorganic salt families with water. They are found with melting temperature from (10 to 900)^{0}C. For low temperature application organic PCM are preferred.

But salts and salt hydrates has higher melting point and comparable latent heat of fusion and higher thermal conductivities. Have higher densities and small expansion during the phase transformation. But the inorganic PCM also has undesirable property of degradation over repeated charging and discharging process. Corrosive and not compatible with most material as well as super cooling property that the material may solidify at temperature below the actual melting temperature. To avoid these problem adding nucleating agent may be needed [48].

3.7.4 Metallic PCM

Different type of metal and their alloys are used as a metallic PCM for thermal energy storage in low medium and high temperature application. Cesium and gallium are used in low to medium temperature application. With melting temperature up to 30^0c tin bismuth and indium are used for the range of melting temperature$(100-200)^0c$, aluminum, zinc and magnesium are used for high temperature application from $(200-400)^0c$ the advantage of using metallic PCM is their higher thermal conductivity, safe and easy to work with. However these material has limitation of low latent heat and high density these result in larger thermal storage container volume.

Even though different variety of material can be used as a medium for thermal energy storage the selection of the material that is used for specific purpose is suitable for the application without causing additional problem to the heated or cooled object as well as the storage container. For the case of our design the application is thermal energy storage for poultry egg incubation purpose. The heating temperature of the incubation process is taken as 37.8^{0}c [48]

Organic, inorganic and metallic PCM discussed above are used in low temperature, high temperature and medium temperature heating and cooling process. Inorganic PCM has property of chemical instability cause chemical reaction with the storage wall and cause corrosion. Inorganic PCM are also thermally degradable with cycle of charging and discharging process. Toxicity is another problem of thermal energy storage system. Mostly inorganic PCM are suitable for high temperature application.

Table 3.2.review types of material that are used for medium temperature.

Type of PCM material	Category	Melting point/heat of fusion	Advantages	Disadvantages
Paraffin wax	Organic	(30-100)c	Non-toxic, non-flammable environmental-friendly, available non-corrosive relatively higher energy density to sensible storage	Lower thermal conductivity resulting in sub cooling, degradable over repeated charging and discharging process
Fatty acids and oil	Organic	(90_150)/100-220	Non-toxic non corrosive, easily drive from crops, low cost	Low thermal conductivity
Water/ice	Inorganic	0	Non-toxic. On-flammable, cheap higher, thermal conductivity	Low heat of fusion, corrosive ,requires larger storage container
Salt and salt hydrates	Inorganic	(10-900)c	Higher thermal conductivity in comparison with the organic PCM	Toxic,corrosive,degradable problem of super cooling below the melting temperature
Metals and metal alloys	Metallic	(30-700)	no problem of thermal conductivity, safe and easy to work with	Low latent heat, higher density requires larger mass of material.

Metallic PCM has higher density resulting in large mass of storage material in comparison to the organic and inorganic PCM.

Since the temperature of heating of incubation process is within the medium temperature heating range. Organic PCM best fit with these process even though it lack good thermal conductivity and flammable. They are chemically stable have higher latent heat of fusion.

Paraffin wax is one of the best type organic material from low to medium temperature thermal energy storage. It is available with varying range of melting point and latent heat of fusion. Fatty acids and families of fatty acids are recommended for low temperature thermal energy storage cold storage for cooling purpose.

Hence Paraffin wax is selected as thermal storage material due to its desirable properties of high heat of fusion, non-corrosive, alert and availability with low cost. From different types of paraffin wax available the one which best fit with heating temperature in incubation process is selected in the following section.

3.7.5 Design Consideration

PCM is placed directly under the absorber plate of the collector as shown on Figure 3.7. This allows direct heat transfer from the absorber plate to the thermal storage system and directly from the thermal storage system to the air when solar radiation is not available or the sunset hour of the day. This eliminate material wastage to construct separate apparatus and accessories used for operating the machine such as inlet fan and the heat insulation required plus other control system. Built in thermal storage system also avoid secondary working fluid loop and reduces the complexity of the system.

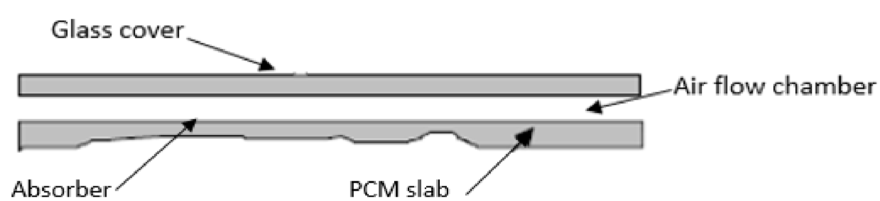


Figure 3.7 Solar air heater with PCM slab as thermal storage system

Paraffin wax is PCM material known for its low thermal conductivity which can result in thermal resistance layer between heat transfer surface and melting front of the wax or sub cooling. It is therefore important to enhance paraffin wax to melt to the entire depth of storage and release all heat stored to the working fluid [47].

3.7.6 Sizing and Analysis of Thermal Storage

Different grades of paraffin wax are available with varying density melting point and heat of fusion. First step in sizing thermal storage system is selecting the right type of storage material from types of paraffin wax for the purpose it is required. One of the method of selecting the material is based on heat of fusion and melting point. Melting point has to be within the range of application it is required for a purpose or the temperature heating /cooling of the system should have to match with melting point of the PCM. The melting point of the PCM should have to be above the optimum operating temperature of the system to be heated in order it deliver the needed amount of energy excessive melting point increase the heat lost from the storage system [47].

The temperature required for incubation or the optimum incubation temperature required inside the egg chamber is 37.8^0c. For the design of thermal storage system for the case of poultry egg incubator paraffin wax relatively higher melting point than optimum operating temperature is selected.

Paraffin consists of straight chains of alkenes CH_3-CH_2-CH_3 solidification of CH_3 release large amount of thermal energy or energy stored in the form of latent heat. The melting point and latent heat fusion increase with the length of chain of alkenes.

One of the advantageous qualities of paraffin's latent heat storage material availability in a large temperature range. Paraffin is safe reliable, predictable, less –expensive and non-corrosive. It is inert and stable below 500^0c, show little volume changes on melting and have low vapors pressure in the melt form [34].

Table 3.3 Physical Properties of Paraffin Wax

Paraffin	Freezing point/range(^{0}c)	Heat of fusion (kJ/kg)
6106	42-44	189
$P116^c$	45-48	266
5838	48-50	189
6035	58-60	189
6403	62-64	189
6499	66-68	189

Source- Energy Sources Journal Volume 16. pp. 117-128, 1994 Characterization of Alkanes and Paraffin [47].

Thermo physical properties of paraffin wax given the table 3.4

Table 3.4 Chemical composition and thermo physical properties of sun tech p116 paraffin wax.

Melting rate	316-329k
Heat of fusion	266kJ/kg
Liquid specific heat	2.51kJ/kg k
Solid specific heat	2.95kJ/kg k
Liquid thermal conductivity	0.24W/m k
Solid thermal conductivity	0.24W/m k
Liquid density	760kg/m^3
Solid density	818kg/m^3
Liquid viscosity	1.90kg/m s
Molecular weight	332g/ moll

Source- Energy Sources Journal Volume 16. pp. 117-128, 1994 Characterization of Alkanes and Paraffin Waxes for Application as Phase Change Energy Storage Medium [47]

ρ_s=density of solid PCM kg/m^3.

C_s=specific heat capacity of liquid PCM KJ/kg k.

ρ_1=density of liquid PCM kg/m^3.

C_1 =specific heat capacity of liquid PCM KJ/kg k.

Based on the above listed criteria paraffin wax with melting point of 47^{0}c which has latent heat of fusions of 266 KJ/kg is selected for the storage system.

The total energy the thermal storage system should have to store depends on the season of the year or it varies with the sun shine duration. However for this analysis average sunshine hour of Addis Ababa is taken. According to data's obtained from Ethiopian metrological service the average sunshine hour for Addis Ababa 6.6. Sunshine is available in Addis Ababa for more than 9 hour but during time there is cloud cover the sunshine hour will be smaller than the expected. Due to its intermittency the smallest possible average sunshine hour is taken for thermal storage system design. So the thermal energy storage system should have to store the required amount of energy for about 17.4 hours.

The incubator is loaded during a day when there is sunshine so that it is heated from the initial state to the required or optimum state. The thermal energy storage system is needed to maintain this condition (the optimum condition that is reached during the day) at that level by balancing the energy loss.

The following assumptions are taken to do the analysis and sizing of the thermal storage system.

Assumptions

- The phases are homogeneous
- The variation of thermo physical properties with temperature with in any phase was ignored due to smaller temperature variation.
- Convection heat transfer does not occur in liquid phase.
- Heat loss or gain from the store is neglected.
- The PCM is initially in solid phase.
- The PCM is homogeneous and isotropic.
- The mode of heat transfer is conduction only.

Heat Loss from the Incubator

Heat loss is the amount of energy that is lost from the incubation chamber in the form of heat. It is lost in different mode of heat transfer from the incubation chamber through the wall as well as through opening used for ventilation.

The following types of loss are expected to contribute for the loss of heat from the incubation chamber.

- Conduction heat loss through the wall of incubator box
- Radiation loss from the incubation chamber
- Ventilation heat loss
- Convection heat loss from the wall

Radiation and convection heat loss from the incubator box is not significant hence it is neglected. Conduction and ventilation loss are considered for design and sizing of the thermal storage system.

Two types of heat loss are considered inside the incubator, Conduction and ventilation loss

Total Heat loss=conduction heat loss + ventilation heat loss

$$Q_{loss\ inc} = 69.9w + 7.5w$$
$$= 76.5w$$

So that the total heat loss

$$Q_{tot} = 80w$$
$$= 80w \times 17.4 \times 3600s$$

$= 4948.56kJ$ Of heat is required for day energy storage.

Q is the total heat stored by PCM material it is $= 4948.56kJ$

Initial temperature of paraffin wax $T1 = 25^0c = 25 + 273k = 298k$

The maximum storage temperature of paraffin wax $T2 = 55^0c = 55 + 273k = 328k$

Melting point $= 47^0c = 47 + 273k = 320k$

Latent heat $= 266\ kJ/kg.k$

From equation 2.1 the total mass of paraffin wax required for the storage of the thermal energy is calculated.

$$Q = m\left[\int_{T_1}^{T_m} c_s dT + l + \int_{T_m}^{T_2} c_l\, dT\right]$$

$$4948.56kJ = m\left[\int_{298k}^{320k} 2.95kJ/kg.kdT + 266kJ/kg + \int_{320k}^{328k} 2.51kJ/kg.k\, dT\right]$$

$$4948.56kJ = m\,(2.95kJ/kg.k(320k - 298k) + 266kJ/kg + 2.51kJ/kg.k(328k - 320k))$$

$$= m\,(350.63\ kJ/kg$$

$$m = 14.1kg$$

Considering certain an expected loss it is important to add mass of paraffin wax to the initially calculated value. Taking 40% percent of allowance the total mass of paraffin wax used for thermal storage is 20kg.

The amount of heat energy stored in the above specified mass of paraffin wax can balance the heat energy lost from the incubation chamber to the environment during the time solar radiation is not available or during the sunset hour of the day. The collector is covered from the top during the night time.

To determine the total volume of the thermal storage system, the lowest density of the PCM in this case paraffin wax is used for the reason that there is change in volume due to expansion of paraffin when it is melted by heating during charging phase. So while designing the thermal storage container it is important to use the largest possible container volume. Hence we can obtained the largest possible thermal storage container volume by using the smallest density which occur when paraffin wax is in its melted state. This is because of volume and density has inverse relationship.

The volume of thermal storage can be calculated from formula of density

Density

$$\rho = \frac{\text{mass(m)}}{\text{volume(v)}} \text{--- [3.58]}$$

$$\frac{760\text{kg}}{\text{m}^3} = \frac{20\text{kg}}{\text{v}}$$

$$\text{volume v} = 0.026\text{m}^3$$

$$\text{v} = 0.03\text{m}^3$$

So rectangular thermal storage tank with length, width and height ($1000\text{mm} \times 500\text{mm} \times 60\text{mm}$) respectively is used as a thermal storage container and it is located under the absorber plate of the solar collector so that the absorber plate is used as a heat exchanger during the discharging and charging period.

3.8 Modeling the Prototype of Solar Egg Incubator

3.8.1 Selection of Material for Construction and of Prototype

3.8.1.1 Selection of Plywood for Wall of Incubator Box

One of the material that is used to construct most of the part of the prototype of the machine is plywood. It is an engineered wood product made by breaking down hard wood or soft wood residual into wood fibers, combining it with wax and a resin binder, and forming panels by applying high temperature and pressure.

Plywood is selected for the construction of the incubator box because of it is availability and it is moderate in cost. It also have desirable property which is low thermal conductivity (high thermal resistivity) this is because low thermal conductivity is desired to reduce the conduction losses from the incubation chamber. It is also used as a back insulation material for thermal storage system and the flat plate collector hence reducing the cost of insulation [42].

3.8.1.2 Egg Tray

Plastic egg tray of holding capacity of 20 egg is used. The purpose of plastic egg tray is to hold egg in the proper position inside the incubation chamber so that the egg get the required incubation condition for hatching. Plastic egg tray of size $[350\text{mm} \times 350\text{mm}]$ is used for holding the egg inside the egg chamber. Plastic egg tray is selected because it is cheap, non-toxic, non-corrosive working at higher relative humidity and stable at the recommended temperature for the incubation process.

3.8.1.3 Iron Sheet Metal for the Absorber

Absorber is sheet metal used for absorbing solar radiation, convert it into heat and to transfer this energy to Air (working fluid). It is also used as a heat exchanger to transfer heat energy to the thermal storage during the charging phase and from the thermal energy storage to the working fluid or air during discharging phase for the case of this specific design. An iron sheet metal of 3mm thickness is used as an absorber.

The upper part of absorber is v- corrugated and the lower part is finned. The upper corrugation increase the heat transfer rate to the air stream and increase the amount of absorbed solar radiation by increasing the effective surface area of the absorber. The fin attached to the bottom of absorber plate enhance complete melting of paraffin wax during charging period and complete release of thermal energy stored during discharging period.

The corrugation is made by welding $[40\text{mm} \times 40\text{mm} \times 3\text{mm}]$ angle iron on the upper surface of the absorber plate. While the fin is made by welding $[50\text{mm} \times 3\text{mm}]$ metal strip on the bottom face of the absorber in order it penetrate in to the thermal mass.

3.8.1.4 Glass is selected for covering the Flat Plate Collector

Cover is require to avoid escape of energy from the absorber plate of the solar collector. Different material can be used as a cover material, glass and transparent plastic are among the common material used in most solar collector as cover material for the collector [7].

Glass is used to reduce or avoid radiative and convective heat loss from the absorber plate, to transmit solar radiation to the absorber plate with minimum obstruction and separate the flat plate solar collector from the external environment.

It is preferred from plastic cover due to its capacity to withstand high temperature without melting and thermal deformation. Another desirable properties of glass is its ability to transmit short wave solar radiation coming from the sun completely and prevent the emission long wave radiation reflected by the absorber from escaping out of the collector [7].

3.8.2 Design Description

The solar egg incubator composed of the following main parts.

3.8.2.1 Flat Plate Collector with Thermal Storage System

The flat plate collector with thermal storage it is $[1000\text{mm} \times 500\text{mm}]$flat plate collector with $[1000\text{m} \times 500\text{m} \times 60\text{mm}]$ thermal storage tanker installed under the absorber plate. The system is also composed of the v-grooved absorber, glass cover, the thermal storage container, paraffin wax as thermal storage material, and the support and inlet air fan driven by low power photovoltaic panel.

3.8.2.2 The Incubator Box

The incubator box it is $[900\text{mm} \times 500\text{mm} \times 500\text{mm}]$ box used to hold egg and to separate the egg chamber from the environment in order the condition are controlled effectively. It consists of the egg tray to hold the egg, water pan for humidification, thermo-hygrometer for measuring temperature and humidity, fan and turning mechanism.

3.8.2.3 The Control Parts

The control parts are components that used to regulate the decisive factor that affect the output of the incubation process. Temperature and humidity are the two factor that have to be controlled and fixed within the range of recommended value. Low power solar panel driven mini fan are used for controlling the factor that have to be regulated during the incubation process. Ventilation is one of the method that is used to control temperature and humidity.

This can be achieved using fan that is used to draw cold and dry air to the system when temperature rise above the recommended value.

3.9 Component of the prototype

The prototype of the machine consists of the support, flat plate collector with thermal storage system, mini fan, incubator box and egg tray turning mechanism, Water pan, hot air flow pipe and thermal storage system.

3.9.1 Support

It is top rectangular box with four legs. The stand is used to support all the component of the flat plate collector. It support the solar collector at 1m length above the ground and inclined at a tilt angle of 24^0. This inclination is used to support flat pate collector at the optimum tilt angle in order to utilize the maximum amount of energy or it is used to support the flat plate collector at angle of tilt 24^0 based on the recommended inclination angle for solar collector for Addis Ababa.

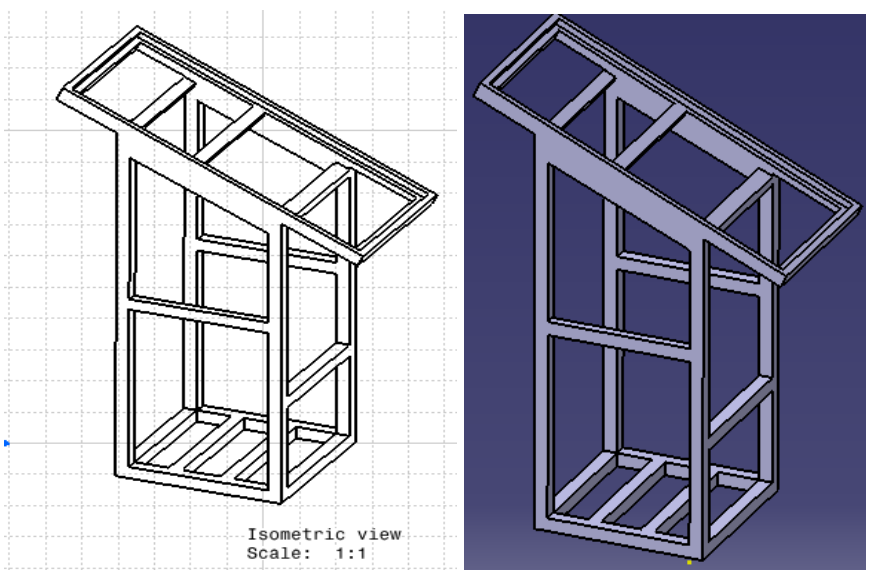


Figure 3.8. Support

3.9.2 The PCM Container

The PCM container [1000mm × 500mm × 60mm] in size and it is used to hold the storage material or paraffin wax under the absorber plate during charging and discharging phase. It is made up of 3mm sheet metal.

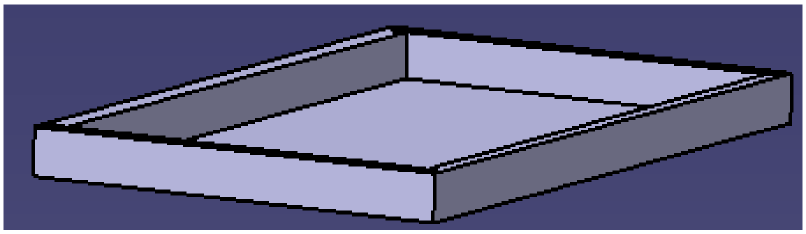


Figure 3.9 PCM storage container.

3.9.3 The Absorber Plate

The absorber plate is the part that is used to absorb solar radiation and to convert into heat energy. Part of the heat energy is used to heat air inside the air chamber of the flat plate collector and the remaining part of heat energy is transferred to the paraffin wax or mechanism which is used to store thermal energy for night time or during sunset hour.

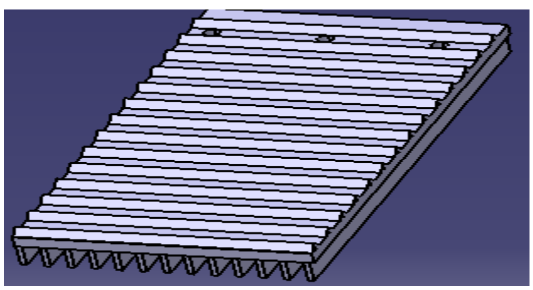


Figure 3.10 Absorber plate with upper corrugation and fin

The absorber plate is [1000mm × 500mm × 3mm] sheet metal. The upper part of the absorber is corrugated with angle iron. The corrugation is used to increase heat transfer process to the air stream flowing over the absorber plate by increasing effective surface area for the heat transfer process. The lower part is finned with sheet metal. Fin is used to avoid solid barrier for heat flow created by freezing from heat loss from the upper part or a part nearest to the absorber plate.

Paraffin wax has undesirable property of high thermal resistivity in the process of discharging. It solidifies on the surface of the heat-exchanger to the side of the discharging face during the discharging process this create thermal resistant wall and become a barrier(insulation) for the flow of heat from the lower part of the storage container to the absorber plate. To avoid these obstacle fin is used. Sheet metal strip is welded on the absorber plate which is used as a fin so that it extract the heat during discharging process and to supply heat to the entire depth of the thermal storage container while charging.

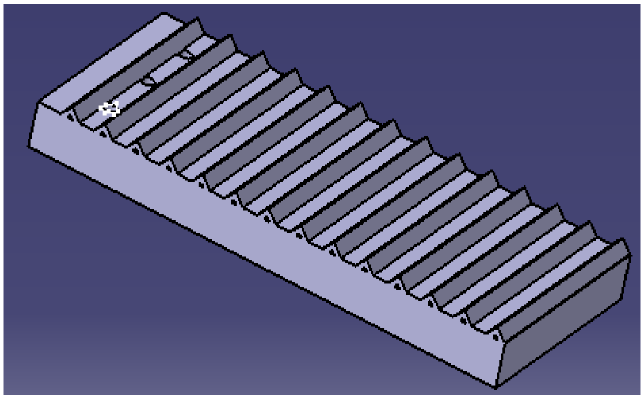



Figure 3.11 Absorber plate with thermal storage system.

3.9.4 The Incubator Box

The incubator box is a part [$\mathbf{1000mm \times 500mm \times 500mm}$] made up of plywood which is used to hold egg and other components to control the incubation condition inside the egg chamber.

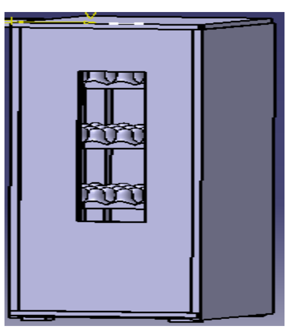


Figure 3.12. The incubator box.

The box of the incubator is used as a boundary which separate the incubation chamber from the environment. This helps to create controlled environment for the egg to be hatched. The incubator box has additional component which is used to support the egg and mechanisms which is used to turn egg over. Egg tray is supported inside the egg chamber**.**

3.9.5 The Egg Tray

The egg tray is part which is used to hold the egg inside the incubator box. Four level egg trays with the capacity of holding 25 egg each is used for the construction of the incubator because of the incubator is intended for incubation capacity of 100 egg.

Figure 3.13. Egg tray

Tilting tray type turning method is used to turn over the egg and to avoid the embryo from sticking to the shell of the egg. To insure this tray should be capable of turning at 45^0 from the horizontal support which is used to support the tray.

3.9.6 Water Pan

As discussed in the literature humidity is one of the decisive factor for the egg incubation process. Humidity is required to avoid dehydration and over loss of water from the embryo in the form of water vapor. Hence it should be controlled with in recommended optimum range. Humidification is achieved by using water pan based on surface area to volume ratio.

Humidity can be increased by adding hot water to a pan is used for humidification of the incubation chamber. Too much humidity is also not recommended. When the level of humidity rise above the recommended value dehumidification is also important. It can be achieved by switching the ventilation fan. Flow of atmospheric air to the incubation box decrease both temperature and humidity.

3.9.7 Fan

Fan is used to pressurize fluid from the outside environment to the flat pate collector so that it is heated and used for heating the egg to be hatched inside the incubation chamber.

Figure 3.14 Mini fan used for ventilation and collector inlet air

It is also used to create pressure difference between the flat plate collector with thermal storage system and the incubator box. The flow of hot air from the collector to the incubation chamber is initiated by the pressure difference between them created by the inlet fan.

The other fan is thermostat actuated fan located at the lower surface of the incubator box. The thermostat switches dc power from the low power photovoltaic panel in order the fan to run and ventilate the incubator to prevent the rise of temperature above the limit. Simple rule is used for the section of the fan. The first criteria for selection of the fan is the type of energy used to drive the fan. Since low power dc panel is used to drive the fan, dc fan should be selected. And the second is availability of the fan in the market. The existing fan should be adopted to meet the need. Hence two dc centrifugal mini fan used in electronics are selected for the air suction at the collector inlet and ventilation of the ventilation of the incubator box.

3.9.8 Solar Photovoltaic Panel

Photovoltaic panel is a mechanism used to convert solar radiation in to direct current electricity. The purpose of solar panel is to drive or run the inlet and ventilation fan. Two 5v mini fan are used for operation of the machine. The first one is to pressurize air from the environment to the solar collector. The second one is thermostat actuated fan used for ventilation purpose.

The selection of solar panel is based on the amount of power required to drive the fan. Hence the solar panel with enough power to drive this two fan is selected. From primary test conducted 3w solar panel with battery storage used for house hold electrification can drive fans. From experiment conducted on the fan the battery storage used for electrification can drive the fan continuously.

Table 3.5 Component of prototype of the machine

Part no	Part Name	Material	Dimension
1	Incubator Box	Plywood	$(\mathbf{2m \times 1.2m \times 0.03m})$
2	Solar Collector Casing	Plywood	$(\mathbf{2m \times 1.2m \times 0.03m})$
3	Thermal storage system container	Iron sheet metal	$\mathbf{1m \times 0.5m \times 0.003m})$
4	Absorber plate Corrugation Absorber Plate Fin	Iron sheet metal Angle iron Iron sheet metal strip	$(\mathbf{1m \times 0.5m \times 0.003})$ $(\mathbf{1 \times 0.006m \times 0.004m})$ $(\mathbf{1m \ \times 0.5 \times 0.003})$
5	Support	Rectangular hollow steel (RHS)	
6	Insulation	Aluminum foil	$(\mathbf{1.5m \times 1.5m})$
7	Egg tray	Plastic	
8	Egg tray support	CHS	
9	Water pan	Plastic	----------
10	Paraffin wax	Paraffin	20kg
11	Dc fan	-------	-------
12	Low power PV panel with battery storage	----------	3w
13	Wheel for movement	Plastic	4 pieces

Prototype of the machine.

Figure 3.15.Photo of prototype of solar incubator.

Figure 3.15 shows the prototype of the incubator box. It is composed of the solar collector with thermal storage system, the incubator box, low power solar panel, fan and other accessories. The thermal solar collector is $[\mathbf{1000mm} \times \mathbf{500mm} \times \mathbf{100mm}]$ sized rectangular box made from wood and a glass cover from the top of the collector.

The absorber of the collector is made from v-corrugated or 90^0 angle iron. It has thermal storage system on the lower part of the absorber. The other component $[\mathbf{900mm} \times \mathbf{500mm} \times \mathbf{500mm}]$ incubator box which is used to store and hold the egg to be incubated is connected the solar collector by the air flow pipe.

3.10 Experimental Method

3.10.1Experimental Setup

Figure 3.16 shows the experimental set up of the experimental machine. The set up shows the solar egg incubator machine with measuring equipment inserted at the place where the data are to be taken. National instrument data logger with labview software is used to measure the temperature of the thermal storage system at different location. One thermocouple is inserted at the lower end of the thermal storage system (8). The second thermocouple is inserted at the middle of the thermal storage container where the PCM material is filled (2). This two thermocouple are inserted at this location to sense and measure the temperature of thermal storage material at different time of charging and discharging period.

The other thermocouple is inserted inside the collector and connected to the absorber of the collector to sense the temperature of the absorber plate. The thermal storage container is located inside the collector under the absorber plate. Hence the absorber plate is used both for absorbing solar radiation and as a heat exchanger to exchange heat that is absorbed to the thermal storage material or paraffin wax. The forth and the last thermocouple is used to sense the environmental temperature. The environmental temperature is used to predict the dependency of the temperature of the storage material.

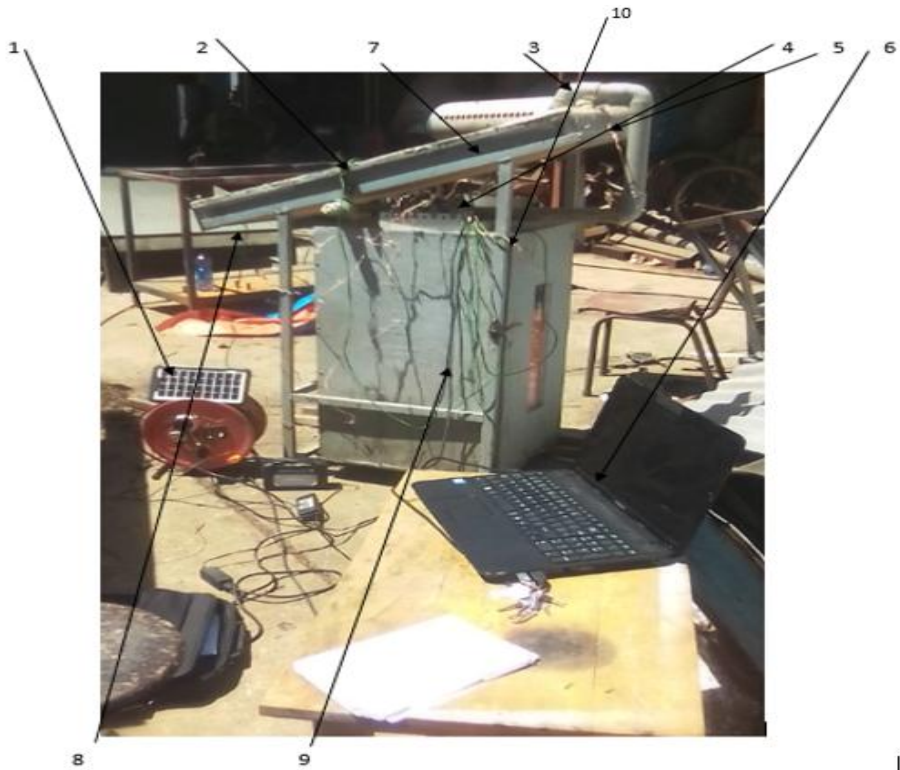


Figure 3.16 The experimental set up of the experimental machine

1. Solar panel with battery 6.personal computer
2. Thermocouple at the middle of storage system 7.solar collector with thermal storage
3. Hot air flow pipe 8.themocouple at bottom of storage
4. National instrument data logger 9.incubator box
5. Thermocouple used to measure the absorber plate temperature
10. Thermocouple used to the environmental air temperature

The other device used for the experimental test is Thermo-hygrometer. It is used to measure both temperature and relative humidity of the incubator box. It is placed inside the box to determine (measure) the conditions inside the incubation chamber were the egg to be incubated is placed.

Low power photovoltaic panel is used to drive the fan which is used for control of the incubation condition such as temperature and humidity.

3.10.2 Experimental Procedure

3.10.2.1 Preliminary Test on Measuring Instrument

Preliminary test is conducted on the measuring instrument to identify the accuracy of measuring instrument. These include checking and calibration of tools. The following measuring instrument are used for measurement in the process of testing the machine

- National instrument data logger with labview soft ware
- Thermo-hygrometry
- Pyranometer.

3.10.2.2 The Experimental Measurement

In order to get the final result the following should have to be performed

- Temperature measurement
- Humidity measurement
- Solar radiation measurement

Temperature measurement

- Ambient air temperature measurement
- Temperature of output hot air from the thermal collector
- Temperature of the incubation chamber or box.
- Temperature of storage or paraffin wax

3.10.3 Temperature and Humidity of Incubator Box.

3.10.3.1 Test on the Incubator Box

An incubator box is a controlled system in which the egg to be hatched is placed and supplied with the temperature and humidity needed for the development embryo within the shell of the egg. The main objective of the research is to supply the incubator with an alternative source of energy and to control the parameters required for incubation with in the recommended range. Temperature is one of the decisive factor that affect the end result or output of the incubation process.

The purpose of test on the incubator box is to identify the effect of change on the ambient temperature on the system or in the internal temperature of the incubator. It was intended to assure that the fluctuation of the most decisive incubation parameter temperature is properly controlled. The other parameter that is measured during the experimental test inside the incubator box is humidity. It is controlled by putting water pan inside the incubator box. Both temperature and humidity is measured using thermo-hygrometer with a digital display. Which shows the temperature and humidity on the screen.

It is a device which is used to measure both humidity and temperature of any given space. The optimum temperature and relative humidity of the incubator is 37.8^0 and 60 % respectively. Humidity is required to resist unwanted water loss or over loss and dehydration of the embryo during the incubation process.

Figure 3.17 Thermo-hygrometer

To avoid dehydration the incubator is supplied with water pan to keep balance of the humidity inside the system. The function of balancing humidity is to resist evaporation and dehydration of the embryo caused by lower amount of humidity inside the incubation chamber.

3.10.4 Test on Solar Thermal Collector

Solar collector is part of the system which is used to collect solar energy. It is a wooden box with upper glazing to prevent heat loss to the surrounding. It also contain corrugated absorber. The corrugation is used to enhance the transfer of heat from the absorber plate to the air stream flowing from inlet fan to the out let of the collector or the heat transfer fluid.

This part of the paper describe how collectors are tested and data are presented. Test on solar collector is done based on ASHREA Standard or devised procedure for solar collector test by US national bureau of standard. Solar collector performance test can be done in three ways.

Determination of instantaneous efficiency based on beam radiation, determination of effect of angle of incidence of the solar radiation and the third is determination of collector time constant and measure of effective heat capacity [7].

The basic method to measure collector performance is to expose the solar collector to solar radiation and to measure the inlet and out let temperature of the working fluid the fluid flow rate.

Air is used as a working fluid to transfer heat from the thermal storage system to the incubation chamber. Ambient air temperature is measured using thermometer. Then the useful energy gain of the collector can be calculated as

$$Q_u = \dot{m}c_p(T_o - T_i) \text{ -- [3.59]}$$

Where m is mass flow rate of the collector c_p is specific heat capacity T_o and T_i the inlet ad outlet temperature of the collector [7]. In addition to collector the wind speed and ambient temperature is measured. This information one for the thermal output and the other for the condition producing that thermal output is used to determine the instantaneous efficiency of the collector.

$$\eta_i = \frac{Q_U}{A_c I_T} = \frac{\dot{M}C_p(T_o - T_i)}{A_c I_T} \text{ --- [3.60]}$$

A_c and I_T are the aperture area and solar radiation respectively ASHREA set forth three standard test procedures for air heaters and liquid heaters.

The essential future of the test procedure is summarized below

1. Means are provided to feed the collector with air at inlet temperature; tests are made over range of inlet temperature.
2. Solar radiation is measured by a Pyranometer on the plane of the collector.
3. Means of measuring flow rate, inlet and outlet fluid temperatures, and ambient conditions are provided.

Experiment made is outdoor. The general test procedure to operate the collector with provided test procedure under steady state condition, measure data for determination of Q_u,T_o , T_i and I_T. That means test are done on clear days free from cloud cover and shadow.

3.10.5 Test on Thermal Storage System

Thermal storage system is used to store thermal energy and to supply it to the incubation chamber when direct solar radiation or sunlight energy is not available. It is charged during the time when solar energy is available. Sun light is available for average sunshine hour of 6.6 for the case of Addis Ababa, so the thermal storage system is charged during this time. During the sunshine hour the incubator uses direct solar radiation or hot air heated by the collector directly from available solar radiation.

It is a $[1000\text{mm} \times 500\text{mm} \times 60\text{mm}]$ storage tank with capacity of storing 20kg of paraffin wax. The loss of energy for the remaining hour of a day is covered by the thermal storage system. The thermal energy storage system should have to store energy for the remaining 17.4 hour. So it is tested for its capacity to discharge the required amount of energy for the specified time period.

The test conducted include measurement and identification of charging and discharging profile using thermocouple inserted inside thermal storage container. These thermocouples are connected to data logger to record the value of temperature at different time of a day.

The test on thermal storage system is done based on the ASHREA standard for testing thermal storage system. The experiment studies heating of paraffin wax inside thermal storage system and the heat transfer process from paraffin wax to air stream which is used to heat the incubation chamber.

The thermal energy storage is a black box that do not alter the composition of fluid passing through it. The thermal storage container it is well insulated to avoid heat transfer to the environment or heat loss. The accuracy of measuring instrument within the value recommended range by ASHREA.

3.10.5.1 Ambient Temperature

Ambient air is the air in space surrounding the collector and thermal energy Storage system. It varies with variation of season of the year as well as variation of the time of the day. The ambient temperature is measured to determine its interdependency with temperature of incubator box, the storage system temperature and output air temperature from the solar collector.

The ambient temperature is factor that affect both the internal temperature of the incubator as well as output air temperature of the collector. So it should be measured and its effect is monitored for correction and readjustment needed to control the interior temperature of the incubator.

3.10.6 Introduction to Labview

Labview (Laboratory virtual instrument Engineering work bench) is a graphical language developed by national instrument for test in Engineering application. Its graphical nature makes it preferable in testing measurement in many areas of work and it increase in productivity.

Virtual instrument VI is a one of lab view’s programming element and it consists of frontal panel, block diagram and icons representing the program .The frontal panel is used to display the control and indicator the block diagram represent the diagram that is coded to conduct the test and measurement. Icon has connectors for input and output of the program.

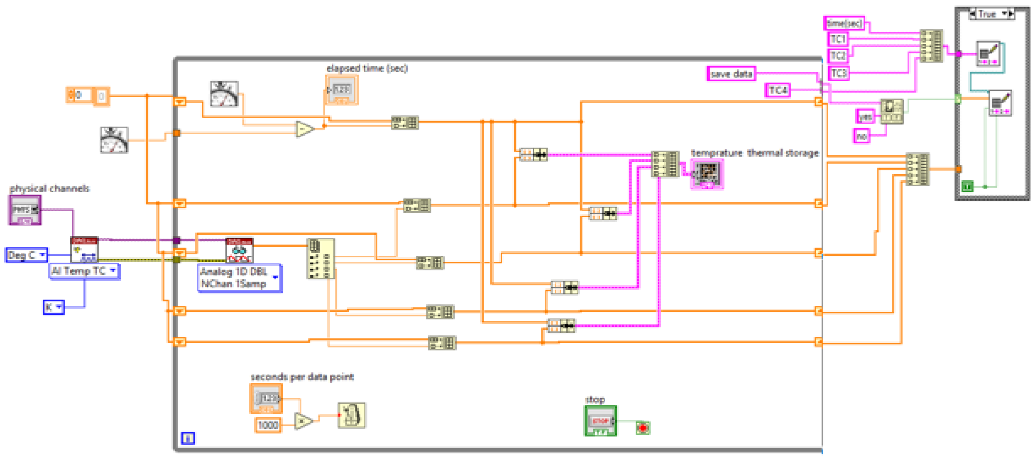


Figure 3.18 Block diagram for temperature measurement in the thermal storage system

Figure 3.18 shows the codded block diagram for measuring, recording, displaying and saving temperature data's of the thermal storage system for both charging and discharging with the variation in environmental temperature. For the case of experimental test conducted for this work, to gate accurate measurement, to conduct accurate analysis of behavior of thermal storage system and to get precise result or value of temperature during charging and discharging period four thermocouples are used. Two thermocouples are inserted at different point of the thermal storage system, one thermocouple to determine the variation of the temperature of the absorber plate and the other thermocouple is used for sensing variation of ambient temperature

The hardware used for the measurement of temperature is national instrument data logger shown Figure 3.19. It is a device developed by national instrument for measurement and test of parameters such as temperature, voltage, current and other engineering parameter that are measured in Engineering application. It has slots used for connecting the thermocouple to the work peace and sensing the reading or result from the thermocouple. The national instrument data logger with labview software has capacity of measuring temperature with in accuracy range of ± 3 with thermocouple connected to the slot of the logger and the work piece.

Figure 3.19 National instrument data logger

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Analytical Result

The analytical design was done based on the thermal energy needed for incubation of 80 eggs and the weather condition data at the place where the test is conducted. From metrological data national metrology agency the average atmospheric temperature and hourly global radiation for horizontal surface for the month October is 17.8^0c and $602.5w$ respectively. From the load analysis 185w of heat energy is required for incubation of 80 eggs. Part of the energy is used for heating the egg and the left is used to replace the amount of heat energy lost from the incubator through the incubator box walls.

Thermal storage with storage capacity of 80w is used to fill the gap of energy need for the time solar radiation is not available. Paraffin wax is used as a thermal mass to store the thermal energy needed. The mass of paraffin wax required for storage of the required amount of thermal energy is 20kg.

4.2 Experimental Result

The first phase of the test was conducted and the problems was identified during the test. Leakage was one of the problem during the first phase of the test. The machine was corrected to avoid leakage. The other problem was the corrugation of the absorber plate. It was arranged in parallel to the direction of flow of air. This result in small heat exchange rate between the absorber plate and the air stream flowing over it. Correction was made on their arrangement of the corrugation in the second phase of the test and improvement was seen in the test result.

4.2.1 Solar Radiation and Ambient Temperature.

Solar radiation is strongly dependent on the location where the system is installed. It is direct or global measured through different time of the day using Pyranometer. The variation of solar radiation with the time of the day is shown on figure 4.1.

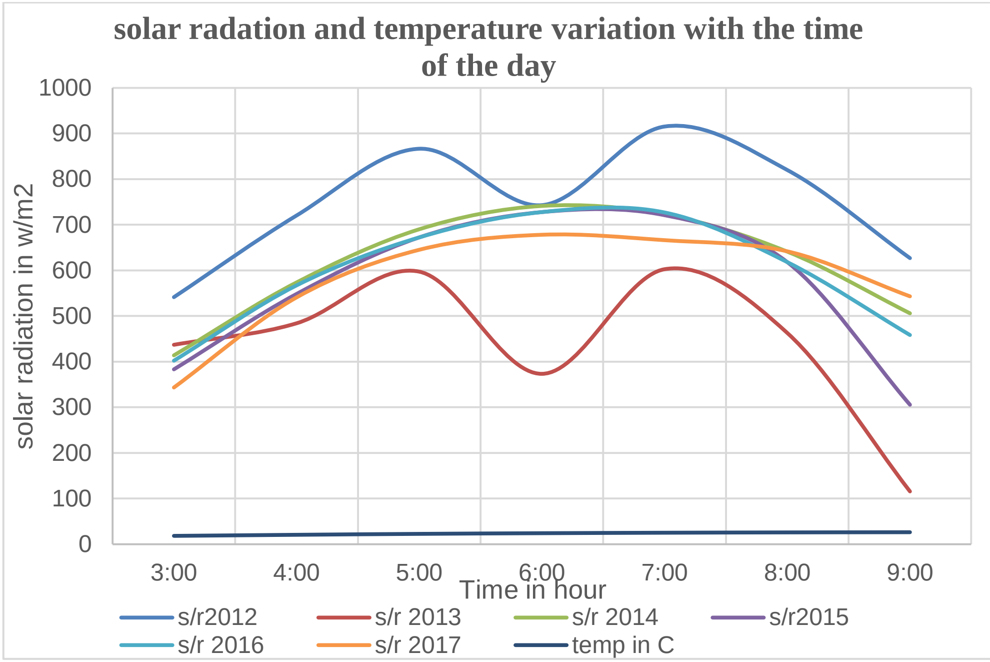


Figure 4.1 Variation of solar radiation with temperature of environment for the representative day of month October from year 2012-2017

4.2.2 Relative Humidity and Temperature of Incubator Box

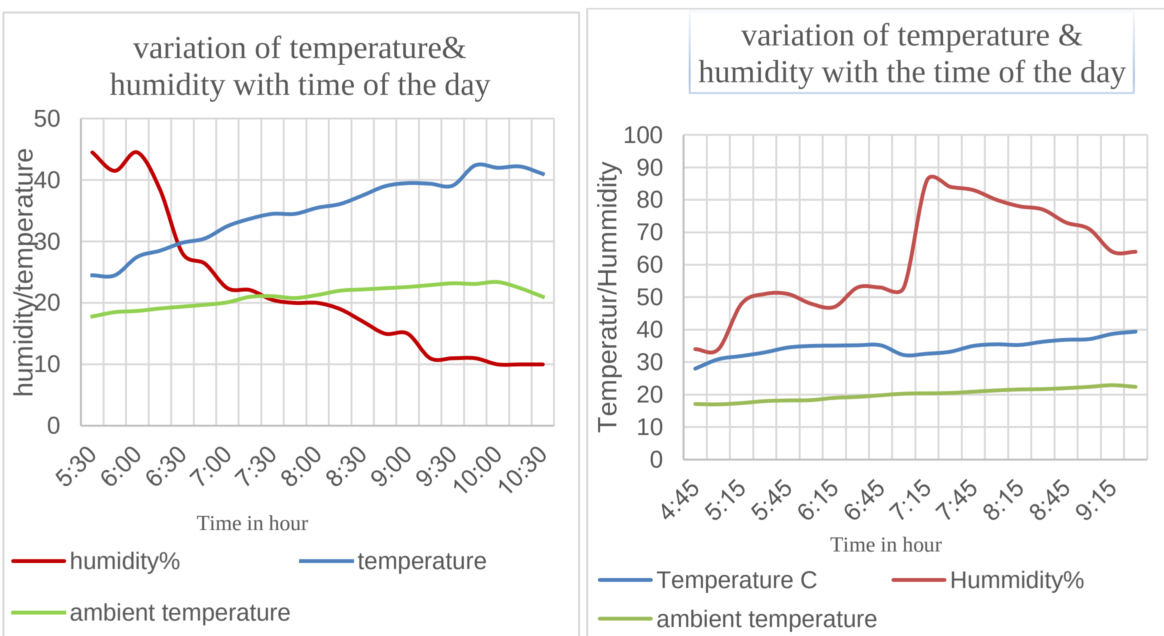
Variation of temperature of the incubator box with the variation in ambient temperature during different time of the day is recorded and analyzed. Thermo-hygrometer was used to measure both the temperature and humidity during the process of testing the machine.

The moisture content of air inside incubator is controlled by putting water pan. Humidity is controlled by adding hot water when it fall below the recommended level and switching on the ventilation fan when it rises above the limit. It uses to prevent over loss and dehydration during the incubation process. Hatching will prevail within range of relative humidity (45-70) %. 60% relative humidity is taken as optimum value for the design in this work. The test was conducted for two days. The first day of the test was without the supply of water pan to determine the variation of humidity with the variation of ambient temperature.

The graph shown in Figure 4.2a shows the variation incubator temperature and relative humidity with ambient temperature at different time of the day without humidification. As it is shown in the figure at the start of the test the temperature of the incubator and ambient temperature was nearly the same. The temperature of the incubator increase gradually with time and humidity decrease. It shows that without humidifier heating the incubator alone will result in decrease of humidity below optimum level. In addition to that from graph below the relative humidity and the temperature of the incubator box has nearly inverse relationship.

Since the incubator type designed in this work is forced air type incubator and it work in an open loop the variation of environmental air temperature has significant effect on the internal temperature of the box. The temperature of the box decrease with the decrease of temperature of the environment.

The figure 4.2b of graph shows the variation of the temperature and relative humidity with supply of water pan for the purpose of humidification. Hot water was added to the water pan to increase the relative humidity when it falls below the optimum range. Addition of hot water result in increase above the optimum value.



a **b**

Figure 4.2 variation of relative humidity and temperature of the incubator box with ambient temperature

One of the objective of the experimental work is to keep the temperature and humidity with in the recommended range of temperature and humidity. At the start of the experiment the incubator box is nearly at room temperature and it increase gradually with time until temperature reach 36.5-39^{0}C.

To achieve this objective ventilation fan is used. To control rise of temperature and relative humidity above 39^{0}c and 60% respectively. This ventilation fan is controlled by manual switch. Low power PV panel is used to drive the DC fan. The operator control the manual switch by reading the thermo-hygrometer. It can be controlled by switching it on and off based on the requirement of temperature and humidity. From the experimental test conducted, once the door of incubator box is opened it takes 3 hour to reach the optimum temperature and humidity.

4.2.3 Thermal Storage System Experimental Result.

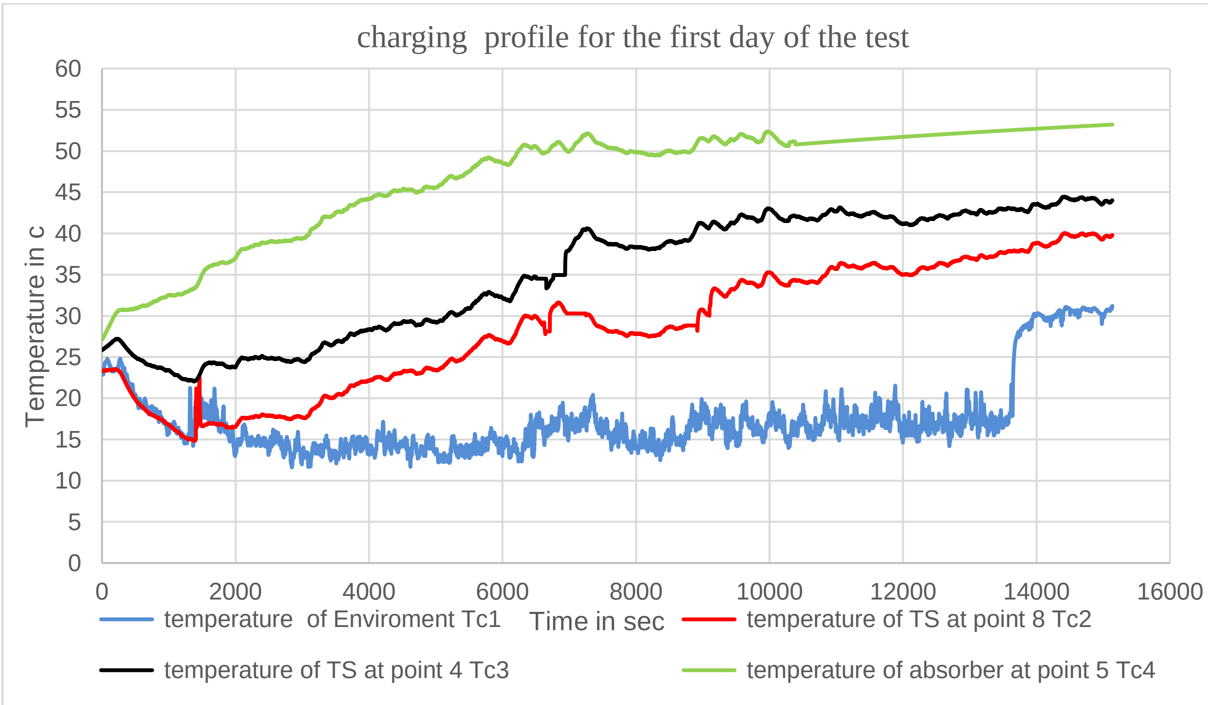
As discussed earlier on this paper the use of thermal storage system is to store thermal energy for night time or the time solar energy not available. It store energy during charging (or during the time direct solar radiation is available) phase and discharge during time direct solar radiation is not available. Wooden box and aluminum foil is used from side and bottom of thermal storage container to minimize heat loss to the surrounding environment.

Test was conducted on the thermal energy storage system to determine the characteristics it shows during charging and discharging process. As it is discussed on the last section of this work paraffin wax was used as a thermal mass for the storage. Experimental data's were taken using national instrument data logger with a labview software. The logger collect data using thermocouple connected to the slot. And it takes data within the accuracy range of ±3.

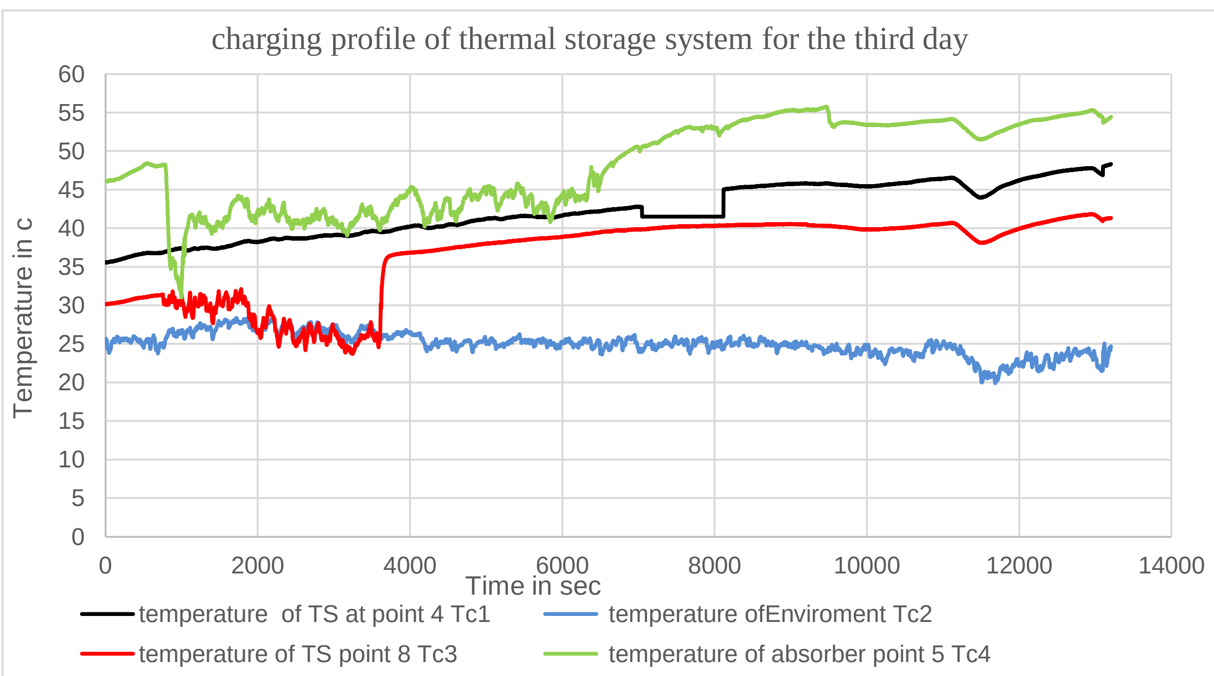
4.2.3.1 Charging Process of the Thermal Storage System.

The Figure 4.3 shows the profile of thermal energy storage during charging phase. It shows the variation of temperature of thermal storage system for different time of the day during charging.

Initially paraffin wax inside the thermal storage system stored at ambient temperature which is lower than the melting point of paraffin. At the start heat is stored inside paraffin wax in the form of sensible heat, as the heating process proceeds the temperature increase to the melting point and paraffin starts to melt and store heat in the form of latent heat or store heat at constant temperature until paraffin completely melt. Further heating it store heat in the form of sensible



a



b

Figure 4.3 variation of temperature at different time during charging phase.

Heat. In other word the temperature of melted paraffin increase storing thermal energy in the form of sensible heat.

The test was conducted for two days for varying time of charging. 3:47 and 5 hours are the times the thermal storage system is charged for the first and second day of the test respectively.

As it was discussed on the experimental set up two thermocouple (no 8 and 4) on Figure 3.16 are used to measure the temperature of thermal storage system at two different point and the third thermocouple (5) is used to measure the absorber temperature. The fourth and the last thermocouple is used to measure the environmental temperature. The temperature profile of the thermal storage system shows almost the same behavior except the length of the time and the maximum and minimum temperature reached.

For the first day of the test, the charging process last for 3:47 hour. The upper green colored line shows the temperature of the absorber plate (5) and the black and red colored line shows the temperature of paraffin wax inside the thermal storage system (8) and (4) respectively. As it is shown on the graph the absorber plate temperature increase rapidly than that of the temperature of paraffin wax. This is due to the smaller heat capacity of iron in comparison to paraffin wax.

In addition to that the absorber plate is directly exposed to solar radiation, this result the absorber temperature increase very rapidly than that of the thermal mass.The maximum temperature of the absorber plate of 54^0c is reached during the first day of the test.

During charging process, the thermocouple inserted inside the thermal storage system near the absorber plate (4) (black colored line in Figure 4.3) reached higher temperature than the temperature of the thermocouple inserted at the bottom (8) (red colored line in Figure 4.3) of the thermal storage container. It shows heat is transferred from the absorber plate gradually to the entire depth of the storage system.

As it is shown the temperature of the thermal storage system and the absorber plate shows little fluctuation with the variation of the temperature of surrounding environment. The environmental temperature varies with the variation of the time of the day and the cloud cover that happen during the charging time of the day.

4.2.3.1.1 The Discharging Process of the Thermal Storage System

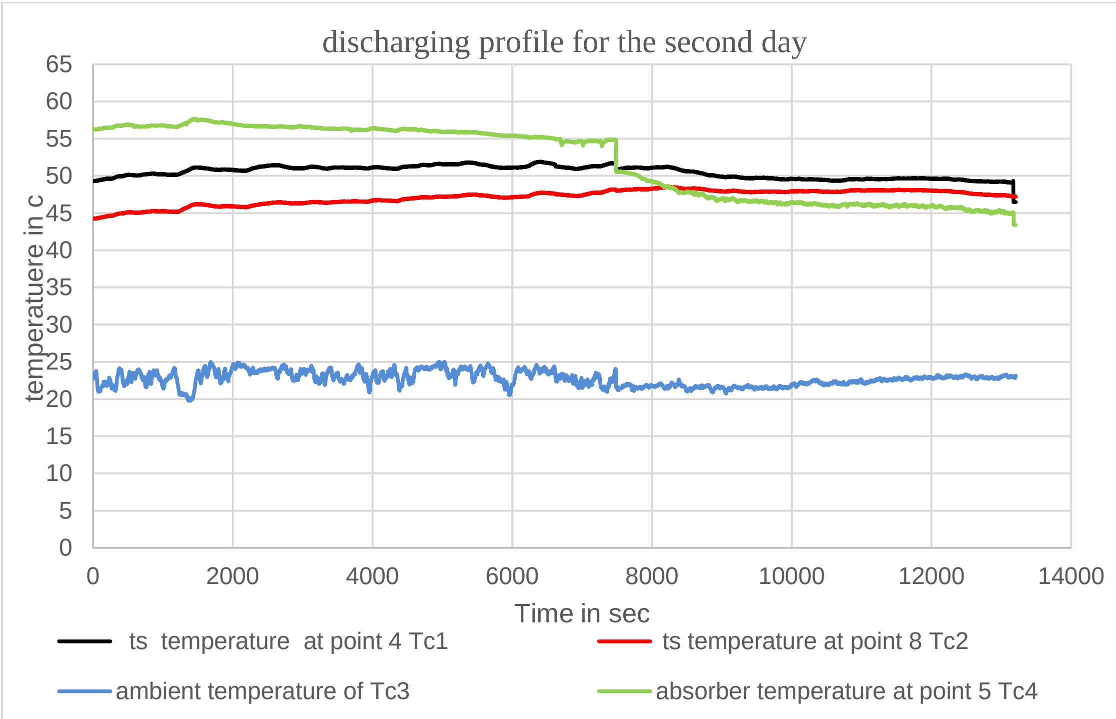
Discharging profile of the thermal storage system is one of the factor that need to be predicted accurately. Thermal storage system is used to replace the heat loss from the incubator box during the time direct solar radiation is not available.

The experimental test during discharging phase of the thermal storage system is to determine the time it takes for the thermal storage system to supply the needed amount of heat energy (80W) before its temperature fall below the application temperature or the temperature of the thermal storage material falls below the recommended optimum temperature.

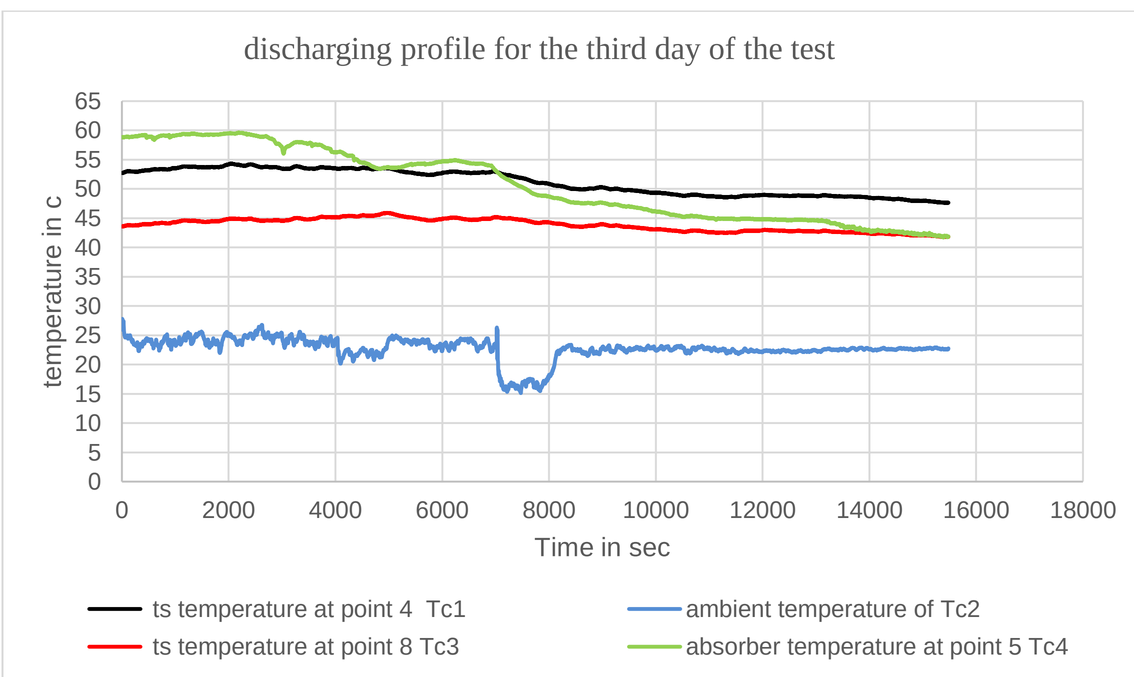
Figure 4.4 shows the variation of temperature of thermal storage system for time of the day for discharging phase. Test on the thermal storage system for discharging is started after charging process is completed. Data’s` for discharging phase was taken during the day time by covering the upper glazing to protect solar radiation from striking the absorber of the collector.

As it is seen from the graph the temperature of the absorber plate, it increase at higher rate during charging phase also drop very rapidly during discharging phase than the temperature of thermal storage medium or paraffin wax. This indicate there is certain draw back on the heat exchanging capacity of the heat exchanger that result from defect during the construction or welding defect and lower thermal conductivity of paraffin.

As it is seen from the graph the discharging profile of the thermal storage system data’s are taken for about five hours. And the storage material doesn’t discharge its thermal energy completely. Hence some other method of prediction is used to get the time taken by the thermal storage system to discharge its stored heat energy before its storage temperature falls below the application temperature.


discharging profile for the second day
65
60
55
50
45
40
35
30
25
20
15
10
5
0
temperatuere in c
0
2000
4000
6000
8000
10000
12000
14000
Time in sec
ts temperature at point 4 Tc1
ts temperature at point 8 Tc2
ambient temperature of Tc3
absorber temperature at point 5 Tc4

a


discharging profile for the third day of the test
65
60
55
50
45
40
35
30
25
20
15
10
5
0
temperature in c
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
Time in sec
ts temperature at point 4 Tc1
ambient temperature of Tc2
ts temperature at point 8 Tc3
absorber temperature at point 5 Tc4

b

Figure 4.4 variation of temperature with time-during discharging phase

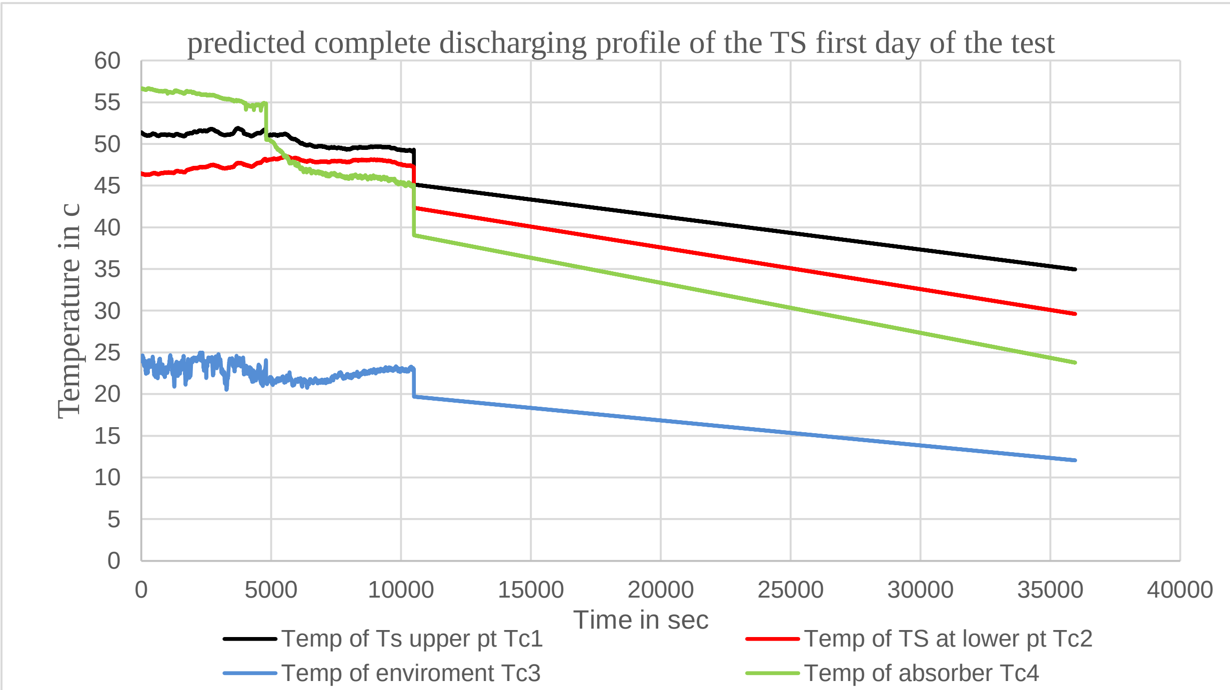
Excel solver was used to predict the complete discharging profile of the thermal storage. Solver is one of the most power full tool for determining mathematical relation and in fitting data to the curve for prediction from the available reference data. Hence from the data obtained for a limited time of the day mathematical relation is derived from the controlled variable temperature and the uncontrolled variable time.

Using the relation from solver the complete discharging profile is predicted. Figure 4.5 shows the complete discharging profile of the thermal storage system. As it is seen from the figure the thermal storage system can discharge its stored heat for 11 hours before it goes below the recommended application temperature. It is assumed that the thermal storage system can be used for heating the incubator box before it goes below 35^0c.

As it is seen from the figure the absorber plate temperature that rise rapidly in the process of charging also decrease very rapidly in the process of discharging. Since the air flow over the absorber plate it release its heat very rapidly than the thermal energy storage material. The low thermal conductivity paraffin wax affect the thermal conductivity from the storage material to the absorber plate. This cause rapid decrease of the absorber plate temperature.

In addition to that from figure 4.5 b in the process of discharging the temperature of the thermal storage material near absorber plate decrease rapidly than the temperature of the storage material at the bottom of the absorber plate. Heat energy penetrate the thermal mass gradually to the entire depth of the thermal storage system. As a result the temperature of the thermal mass near the absorber plate heated and melted in faster rate than the bottom. So that the temperature of the thermal storage system during discharging phase it release its thermal energy at faster rate since it release the stored heat thorough the absorber plate. The nearer the thermal storage material to the absorber plate the faster its discharging.

a.



b

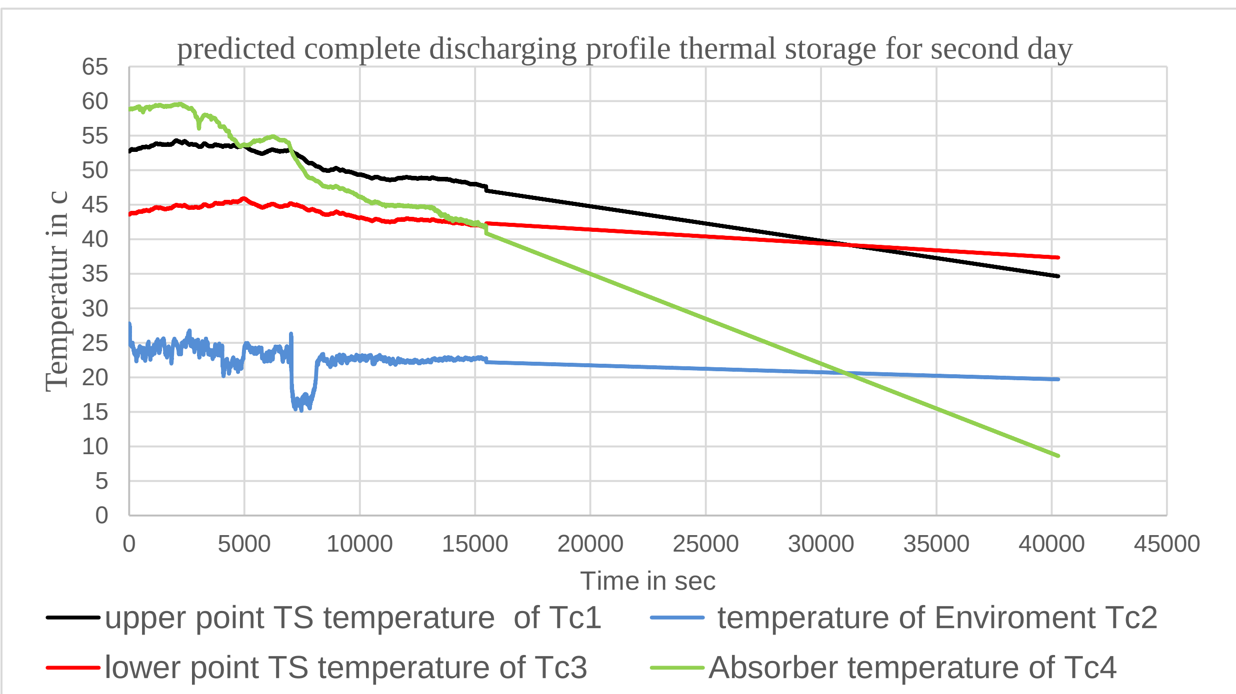


Figure 4.5 Predicted thermal storage discharging profile

4.2.3.2 Experimental result of the collector

Experimental test is conducted on the collector to determine its efficiency. The test include measurement of temperature of absorber plate, temperature of inlet hot air and temperature hot air at the outlet of collector.

According to the standard used to test thermal storage system that is discussed in chapter three the output hot air temperature and the useful energy gain is used to calculate the efficiency of collector. The useful energy gain of flat plate collector is calculated using the inlet and outlet temperature of the collect.

And the efficiency is calculated from the collector area and useful energy gain using equation 3.60.

$$\eta_i = \frac{Q_U}{A_c I_T}$$

$$= \frac{\dot{M} C_p (T_o - T_i)}{A_c I_T}$$

$$= 49.6\%$$

This result is reasonable and it is validated with work that are done in the past with scholars. M.Alkilani et al [33] reported efficiency of flat plate collector between 27% and 69%. M.A Wazad et al [54] reported efficiency of 63%.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this research design construction and testing of solar egg incubator is discussed. As it is discussed on the methods of the research the machine works integrating solar thermal collector with low power photovoltaic panel. It uses solar thermal energy for heating and solar photovoltaic panel to drive control parts fan in order to monitor the condition require for the process. Fan is also used to pressurize air to the air chamber of the solar collector. It can be used in rural areas where there is no grid provided electricity.

The approach to achieve the objective of the research involve data collection, synthesis and analysis to get the possible amount of energy that can be harvested at the study location. Sizing the flat plate collector based on the load or energy needed for incubation and amount of energy that can be harvested, geometric modeling and finally construction and testing of the machine is done.

The machine is composed of multiple components working together to give the required function or the expected outcome. It has $[900\text{mm} \times 500\text{mm} \times 500\text{mm}]$ incubator box with a four level egg tray with a total holding capacity of 80 eggs. The box has a DC fan which is used to supply with the necessary ventilation air for the eggs .The ventilation air prevent rise of temperature and humidity above the recommended value.

From the load analysis on the incubator the 185w of heat energy is required for incubation of 80 egg. Based on the metrological data, the result from analysis show that $0.5m^2$ area of flat plate collector can supply the needed amount of thermal energy.

The absorber of the thermal collector is corrugated to increase flow obstruction and enhance the heat transfer process from the absorber plate to the heat transfer fluid or air. Directly heated air is used for heating the incubator during the day time. $[1000\text{mm} \times 500\text{mm} \times 60\text{mm}]$ Sized thermal storage container is located under the absorber plate of the machine to assure the supply of energy for the remaining hour that solar radiation is not available.

In the process of testing the machine temperature and humidity of the incubator box, temperature of thermal storage system during charging and discharging process at different point of the container, output air temperature from solar collector and ambient temperature is recorded. Efficiency of solar collector of 49.6% was obtained from the test conducted on the flat plate collector with a v-grooved absorber.

Result from the test shows that the temperature of the incubator box varies with the variation in ambient temperature. From the experimental test conducted the internal temperature of the incubator is dependent on the environmental temperature it falls to minimum value during the time when solar radiation is not available or the temperature of the environment decrease to the minimum value.

These is because the output air temperature falls decrease with decrease in temperature of the environment since the inlet fan draw air directly from the environment. It can be maintained with in the recommended range using temperature controller such as ventilation fan and humidifier (water pan is used for humidification) even though there is small fluctuation from the optimum temperature and humidity.

The test on the thermal storage system revealed that the temperature of the PCM inside the storage container and the speed in which it is charged and discharged depend on the intensity of solar radiation and the ambient temperature. The thermal storage can store thermal energy for about 11 hour if it is fully charged with air flow rate of 0.0037kg/s. N. Mahla and A. Yadav[55]reported thermal storage with paraffin wax can discharge thermal energy for 6 hour with a flow rate 0.018kg/s with temperature fall from 330k to 310k. In addition from the result the experiment they conduct the flow rate and the storage time has inverse relation the working fliud flow rate the smaller the storage time and vice versal. The storage time predicted from the initial test result is reasonable and valid.

In general the test conducted on the solar incubator and on its component reviled that the solar powered egg incubator can work effectively within in the recommended range of temperature of 36 to 39^0c. It can be kept within this range of temperature with the aid of control mechanism. Hence the incubator can work temperature with in the recommended range and it is validated according to French .N.A [13], Lourens [23].

Hence this study shows an option for the hatching process in village poultry industry using renewable energy resource. This has advantage of increasing the production efficiency by increasing the production number if it is implemented with additional detail study and improvement.

Finally if this work is implemented it makes the rural community of the country the potential beneficiary and it will play significant role for livelihood improvement and increasing income.

5.2 Recommendation

On this work design construction and testing of solar egg incubator is done. From the test conducted on the machine to identify whether the machine can supply the necessary condition for the incubation of the egg.

The test conducted in the work was to predict the factors that affect the temperature and humidity of the incubator box and to investigate the discharging profile of the thermal storage system. The result obtained from the test is promising. From the preliminary experimental test the following factor are listed as recommendation for the future work to be done in this research area for further future time improvement.

1. Both the temperature and humidity of the incubator box depend on the temperature and humidity of the surrounding environment. Since the collector box inlet fan draws cold and dry air directly from the surrounding environment and it work on an open loop. Working on an open loop result in higher thermal loss both from the collector and the incubator box. In the future work to be done in this area of research to avoid loss from the incubator box and to reduce the heating load required in the solar collector as well as to reduce the loss from it. Considering the system to work on a closed loop as an option may result in improvement in the work to be done in the future.
2. Preliminary test is conducted to identify whether the machine is capable of supplying the conditions needed for incubation. But incubation is continues process of about 21 day longer. The actual test requires testing the incubator for 21 with full load. The full

load test is not conducted due to financial and time constraint. For further improvement in this research area in future it is recommended that to conduct the test at full load for 21 day.

3. Solar energy is intermittent in its nature or the availability of the solar energy varies with variation of time of the day and seasonal variation. Thermal energy storage system is used to fill the gap of need of thermal energy for the duration of time the direct solar radiation is not available. But availability of solar energy is very small during the summer time or for the months from end of June to the binging of September due to cloud cover on the sun. Hence this machine cannot be used during this time since the intensity of solar radiation during this time is very low and incapable of charging the thermal storage system, so if the machine is intended to give function during this time (from end of June to end of September) the year considering additional heating mechanism is recommended.
4. The control of temperature inside the incubation chamber by using ventilation fan. The ventilation fan should be controlled by manual switch. However controlling the temperature by manual switch may reduce the efficiency of the incubator. The design of the machine was done considering use of small dc thermostat for control purpose. However, since it is not available in our market it cannot be used on the construction of the prototype. Since thermostat has temperature sensing capacity it is programed to actuate the fan when temperature rise above the recommended range. Small dc thermostat was intended for this work because of the power source used for operation of the fan is low power PV panel. But Dc thermostat is not available in our market instead manual switch is used. For future work it is important to purchase and use dc thermostat to make the control method efficient and simple.
5. Form the experiment conducted in the thermal storage system discharging process the temperature of the absorber plate is decreasing rapidly in comparison to the temperature of the thermal storage material paraffin wax. This result from the lower thermal conductivity of paraffin wax. Sub cooling is one of the main drawbacks of PCM material that occur due to lower thermal conductivity. Sub cooling is a phenomenon that the storage material that is near to the heat exchanger (in this case the absorber plate)release heat and creating thermal resistance layer in the heat

exchanger creating heat resistance barrier for heat transfer from the bottom of the thermal storage container. One of the recommended methods of avoiding sub cooling of PCM material is adding thermal conductivity enhancing material to the PCM material for future work on selecting best thermal conductivity enhancing material is recommended to solve the problem of sub cooling in the thermal storage system.

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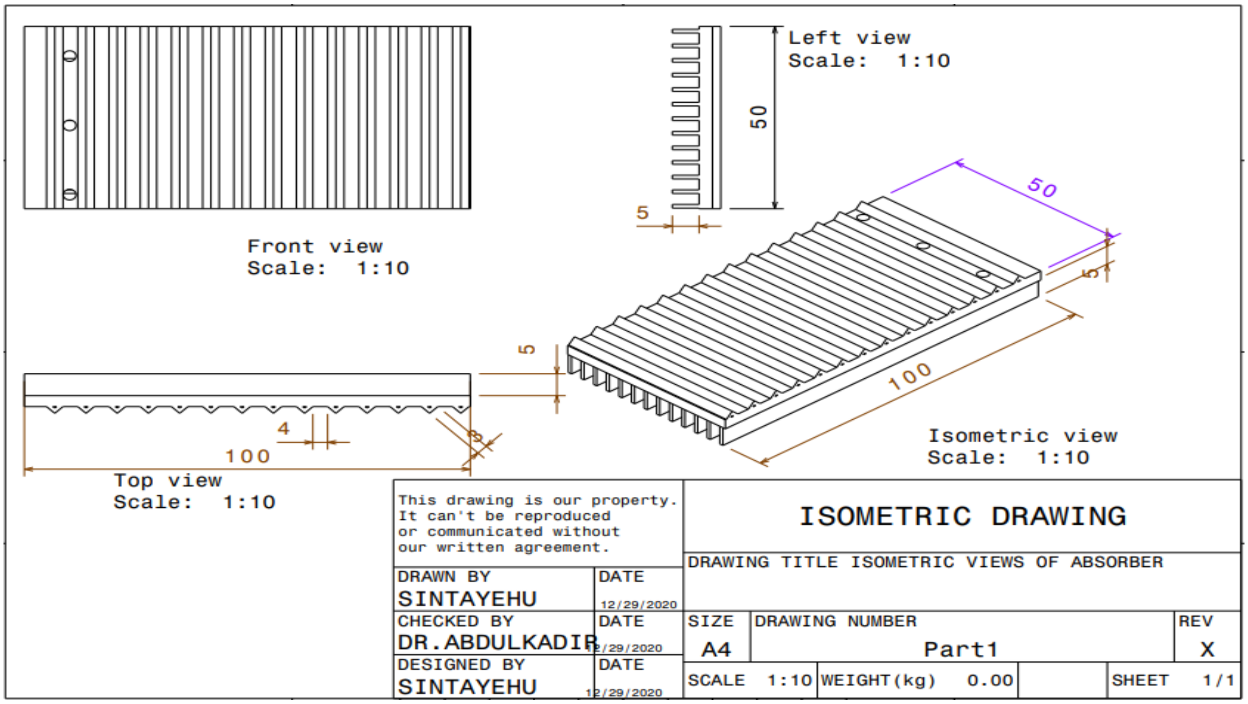
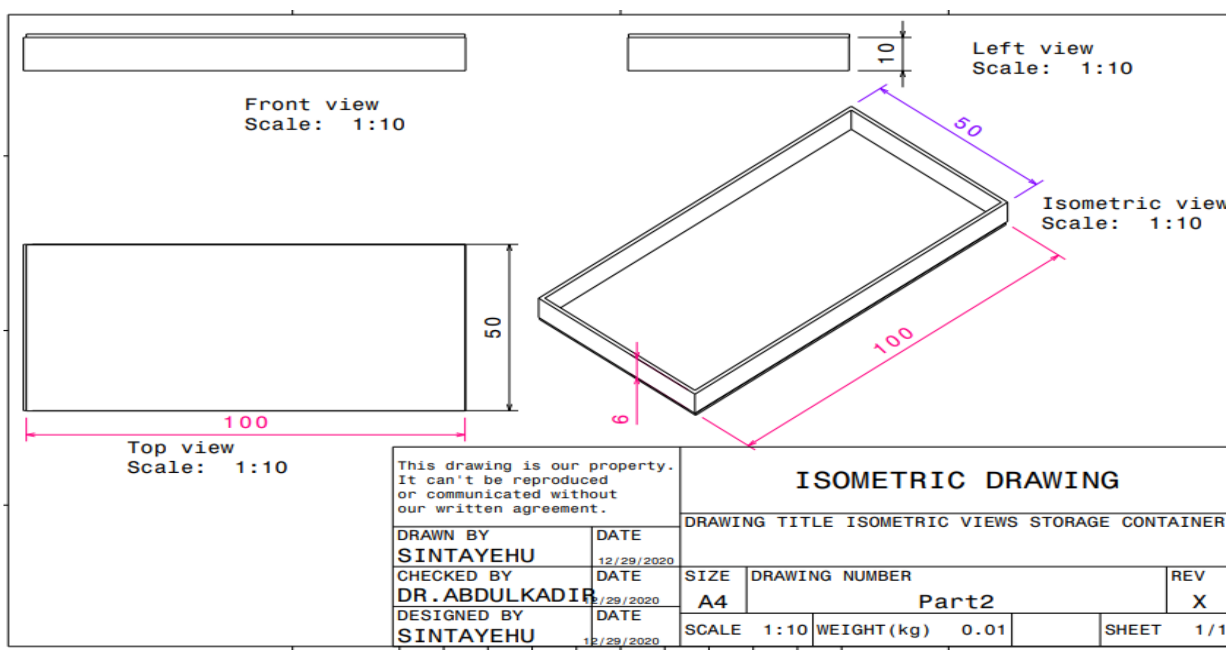
APPENDIX

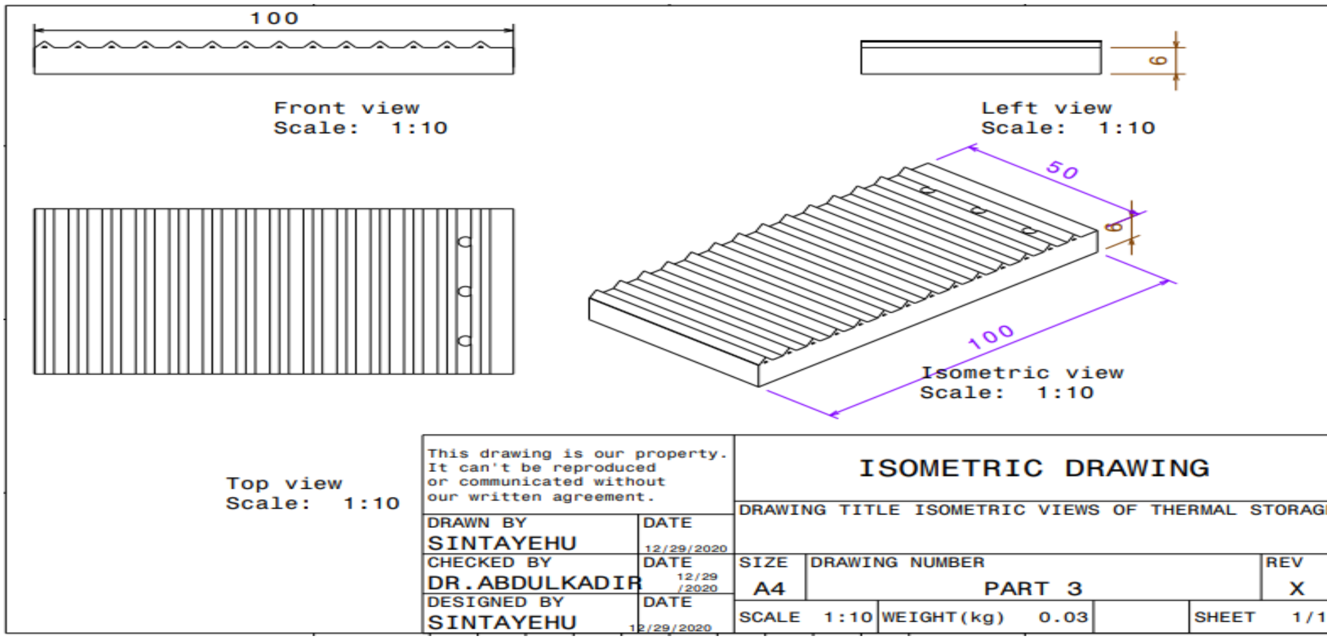
7.1 Absorber



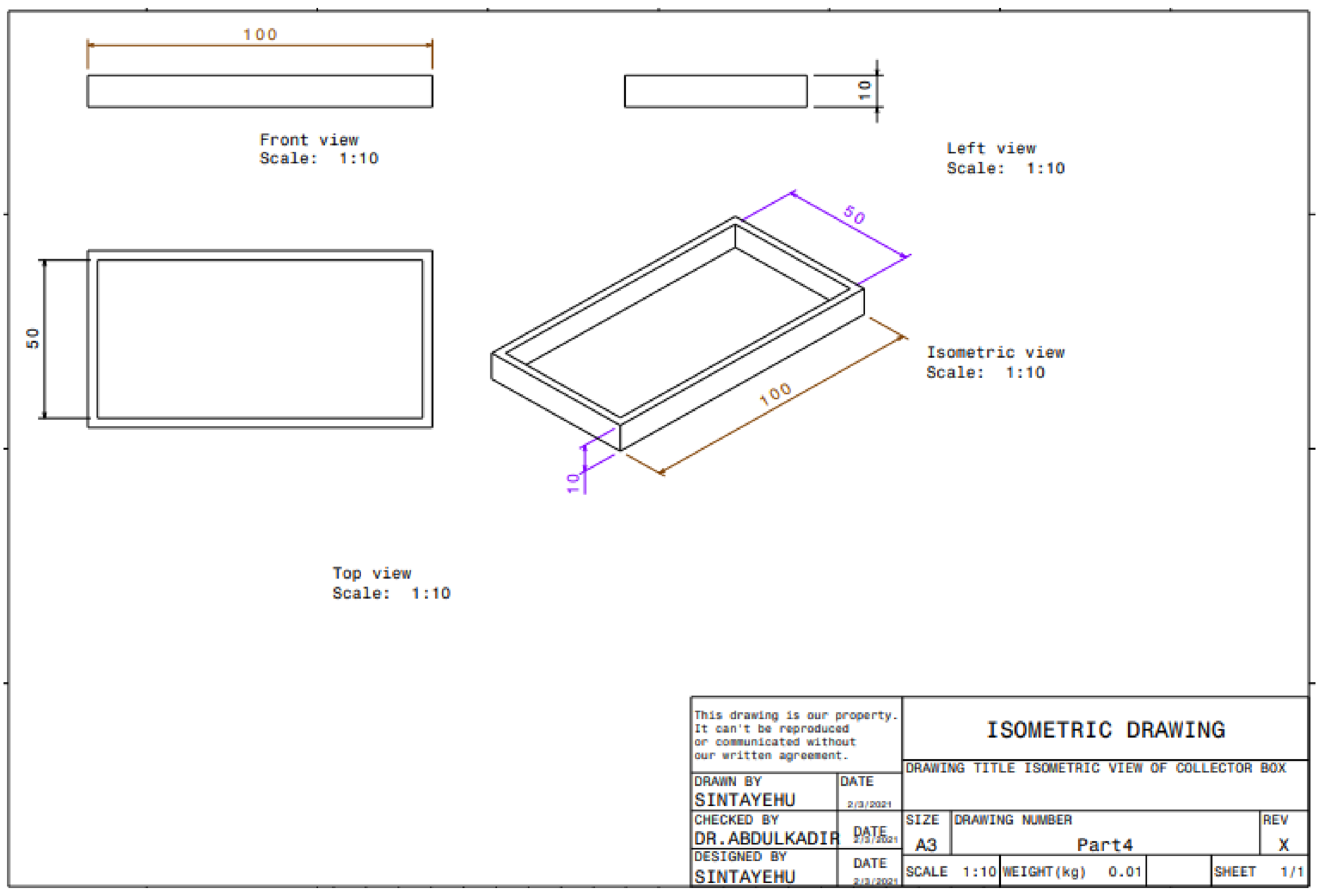
7.2 Thermal Storage Container



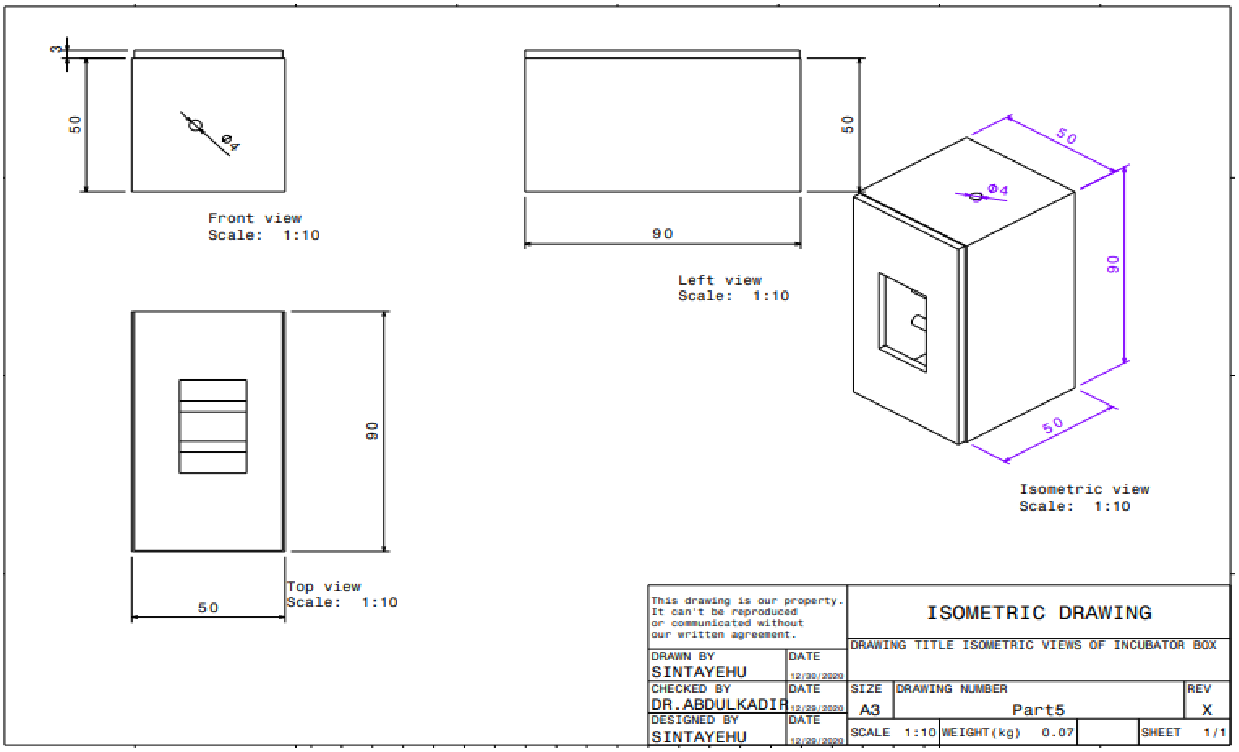
7.3 Solar Collector Box



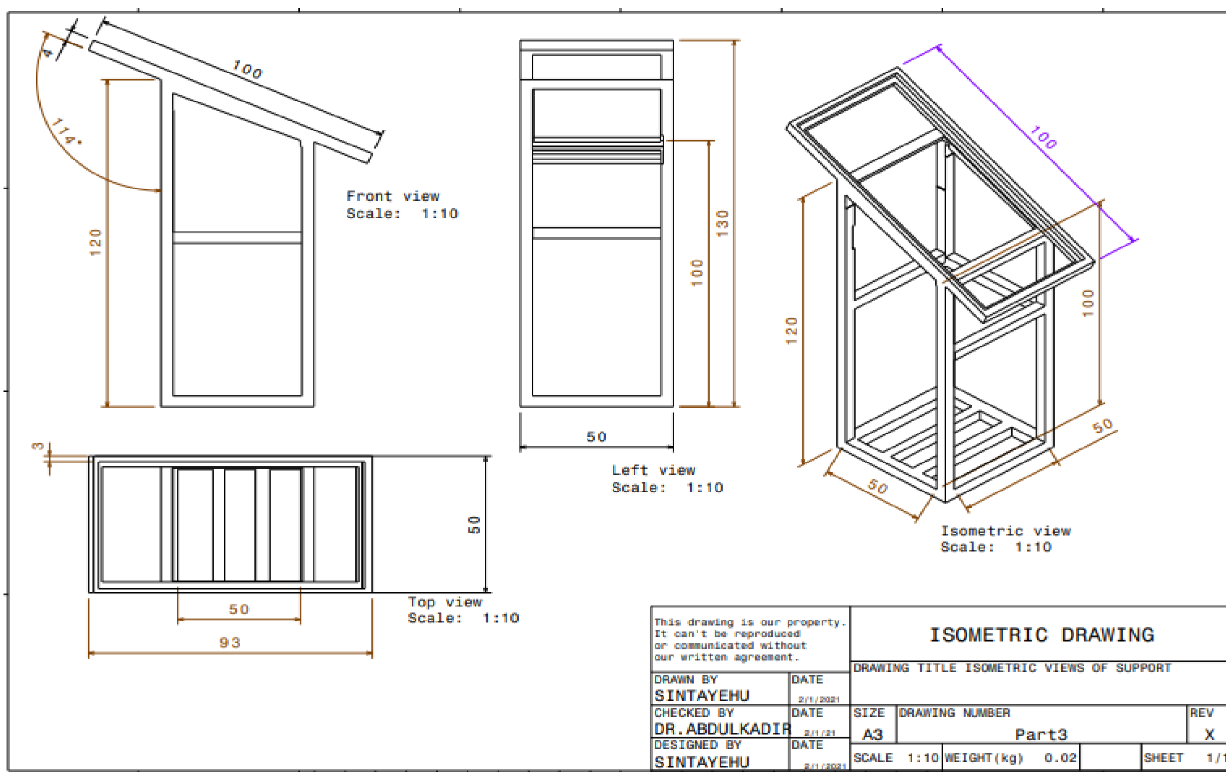
7.4 Solar Collector Box



7.5 Isometric Drawing of Incubator Box



7.6 Support



7.7 Isometric Views of Assembly Drawing