DEVELOPMENT OF A FISH SOLAR DRYER

BY

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DEDICATION

This project work is dedicated to my late father Mr Enejoh and my darling Mother Mrs.Enejoh.

ACKNOWLEDGEMENT

I acknowledge the Almighty God for sustaining me to this level of the programme. All thanks to God for the protection and provision all through the course.

There is hardly an academic work carried out successfully in isolation, to this, I am inevitably indebted to my project supervisor, Engr. Dr (Mrs) Z.D Osunde for her constructive criticism in the course of writing this project. Also my gratitude goes to the Head of Department, Engr. Dr. D. Adgidzi and other competent lecturers in the department of Agric. Engineering whom I have one time or the other passed through their tutelage.

More so, my gratitude goes to the Principal and the entire staff of Baptist model High School for the Psychological support and prayers. May the Almighty bless you abundantly.

So much for this, I reasonably appreciated my course mates for their cordial relationship in the course of this study. The Lord bless you all.

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Many other people which space cannot permit me to mention have contributed in the course of this programme. May the Almighty God reward them abundantly.

Enejoh, Jeremiah Monday.

ABSTRACT

Fresh fish is one of the most perishable food. Fish spoils quickly because of the high ambient temperature in the tropics. Hence fish preservation is an important aspect of fish processing technology therefore, a fish dryer will be needed. The aim of this work is to design and construct a reasonable size solar dryer to be used for fish drying. The capacity of the designed solar fish dryer is for 40 fishes which is an average capacity and an average temperature of 55^0C was recorded in the drying chamber of the dryer. The result showed that the dryer could reduce the moisture of fish as low as 10.8% in 12 hours. The average pick-up rate of the dryer was found to be 0.186kg/hr.

TABLE OF CONTENT

LIST OF SYMBOL

Symbol	Description	Unit
δ	Angle of declination	0^0
n=	Day number which varies from first of January to December	days
φ =	Latitude value for Minna	0
ω =	Hour angle	
∞=	Surface azimuth angle	0
β=	Slope angle	0
Ic =	Isolation intensity	w/m^2
I/c =	Collection Efficiency	%
Cp =	Specific heat of air	$JKg\text{-}^{1}0_{C}^{-1}$
f. =	Effective Transmissivity absorber product of cover &absorber	
Ac =	Collector Area	m^2
ρ =	Arrolensity	Kgm^{-3}
V =	Volumetric flow rate of air	$M^3\ S^{o1}$
Ta =	Air Temperature	^0C
Tp =	Water Temperature	^0C
Ut =	Loss Coefficient	N/M^0C

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

For thousands of years, people have made not only simple but economic way of preserving fish. During the process of drying, water is removed for the prevention of fermentation. There are various methods of drying fish namely: Salting, Sun drying, Smoking, use of Kerosene, Electric oven etc.

Many years ago, the main method used in the drying of fish was by placing then on trays or mats in the sun. This usually takes days before proper drying is accomplished. By using this method fish could be contaminated by dust, mold, fungi, insects, and may be consumed by other animals.

Fish have formed a large portion of man's food because of their abundance and relative ease of catching. This high demand for fish is not only because they are good but they are for all types of menu and can be cooked and preserved in a wide variety of ways. This high demand for fish calls for a good preservation since fish is often caught at some distance from the location which are not highly consumed.The use of solar fish dryers is an alternative to other method of drying with Sun being its source of energy. This source of energy has two factors in its favour. Firstly, unlike other sources of energy such as fossil fuel and nuclear power, it is on environmentally clean source of energy. Secondly, it is free and available inadequate quantity in all parts of the world.

One problem associated with the use of solar fish dryer is the variation in the availability of solar energy with time.

Solar fish dryer produce better looking, better tasting and better quality dried fish. They are also faster, safer and more efficient than the traditional sun drying techniques where the heating effect of the sun is not concentrated properly on the fish. Drying by electric Oven is the most efficient of all the methods, but it is limited to the urban areas where there is constant supply of electricity.

1.2 ADVANTAGE AND DISADVANTAGES OF THE SOLAR FISH DRYER OVER OTHER ALTERNATIVES

1. It is faster, fish can be dried in a shorter of time solar dryer enhances drying time in two ways namely The translucent or glazing over the collection area traps heat inside the dryer, raising the temperature of the air. Hoyt (1974)
2. It is more efficient, since fish can be dried more quickly.
3. It is safer since fish is dried in a controlled environment, they are less

likely to be contaminated by pests, and can be stored with less likelihood of the growth of toxic fungi

4. It is healthier. Drying fish optimum temperatures and in a shorter period of time enables them to retain more of their nutritional value. An extra quality is that fish will appear better and taste better, with enhances marketability.

5. It is cheaper: using solar energy instead of conventional fuel to dry products, or using a cheap supplementary. Supply of solar heat in reducing conventional fuel demand can result in a significant cost saving. Solar drying lowers the cost of drying, improves the quality of products and reduces losses due to spoilage.

DISADVANTAGES

Solar fish dryer do have short-coming; they are of little used during cloudy weather. During fair weather however, their efficiency is high and become so hot that it can burn the fish. Only with close supervision can this be prevented.

1.3. SOLAR DRYER PERSPECTIVE

Survey from the past work on the solar dryer reveals that generally, there are two principal aspect of the fish drying process

a. The solar heating of the working fluid (generally air)

b. The drying chamber therein the heated air traps moisture from the fish to be dried. Hoyt (1974). The solar heating function consists of:

i. Separate solar heater collectors using natural or forced convention to preheat the ambient and reduce its relative humility; and

ii Direct, in–situ, heating of air which in turn directly dehydrates the produce.

It was generally observed that all the past design of solar dryers are based on the principles listed above one of these observation was noted too recent ago.

It was noticed that the capacity of the dryer was very low and it took days for the fish to dry properly. This was so because of the following reasons:

- A single layer of glass was used
- Provision of vents
- Size of the dryer
- Formation of dew in the heating chamber

1.4. OBJECTIVE OF THE STUDY

The general objective of this project work is to design and construct a reasonable size solar dryer to be used for drying fish. The temperature in the drying chamber will be projected between an average of 40^0C - 60^0C. Contamination of the fish will be reduced to minimum.

The Specific objectives are:-

1. To design a solar fish dryer
2. To construct the unit from locally available materials so as to make it affordable to the rural farmers
3. To test the unit in order to determine its performance with respect to its drying rate and capacity.

CHAPTER TWO

2.0 LITERATURE REVIEW.

2.1 DRYING

Drying is one of the process by which agricultural products are preserved. It is carried out to prevent spoilage. Drying is a process of simultaneous heat and moisture transfer. The heat is needed to evaporate moisture from the product. These two, heat and moisture must be transported and this is usually done by air Ajisegiri (2001).

The use of solar energy have a great potential for improving agricultural drying operation around the world. At present, a large portion of the world supply of dried fishes, fruits, vegetable and grain continues to be sun dried in the open air under primitive conditions being unprotected from unexpected rains, wind, dirt and dust, and also from infestation by insects rodents and other animals. The quality is often seriously degraded, some times beyond edibility. Jegede (1993).

UNIFEM (1988) recorded that different methods have been used by different people to achieve this goal. These methods include sun drying, salting, smoking, boiling and fermentation. In many countries, the methods used are a combination of the above techniques. In addition, two process termed similarly may involve quite different techniques as applied in different countries, for instance "smoking" may mean simply throwing the whole fish out of a pit, fire in one locality, where as in another it may involve salting and drying before smoking.

Ajisegiri (2001) stated that, at present most rural farmers believed that solar drying is synonymous with sun drying. Although both rely on sun as their source of energy, solar drying differs from sun drying in many ways. In a solar dryer, produce could be directly or indirectly exposed to sun energy. In both direct and indirect solar drying a kind of structure or device to harness the energy, no matter how simple, is involved. Where as sun drying utilizes direct in insolation.

2.1.1 Comparison between Solar drying and Sun drying.

A solar dryer can generate higher sensible heat than sun drying process. Consequently, solar dried products tend to have better product quality and consistencies compared to sun dried products due to their higher rate of evaporative capacity. Unfortunately most rural farmers could not distinguish between the two and so any solar based process is interpreted to mean sun drying and the products are treated as such.

Solar dryers could generate higher temperature and hence lower moisture content could be achieve in the dried product compared to sun drying thereby resulting to higher quality of products. In sun drying, it is customary to spread the produce in a thin layer (most likely mono layers) while with solar drying this is eliminated.

2.2 SOLAR DRYING

Solar dryer have developed world wide as a means of concentrating solar energy for drying or cooking and other process. There are two methods of concentrating solar energy for drying or cooking and other purposes. One is based on concentrating solar energy by a parabolic shaped reflector mirror into a substance where the temperature becomes higher. This method is usually used for solar cookers and has not been applied to fish drying. Fang and Swannnack-Nunn (1979).

The second method is the solar dryer, which depends on concentrating of radiation through plastic or glass surface, combined with the green house effect for trapping heat within a small unclosed where fish is placed.

The trapped solar energy heats up the air, which increased its drying efficiency by reducing relative humidity in the enclosure. The energy retained by the heated air is used to evaporate the moisture from the fish. This evaporation along with the normal evaporation of the moisture from the fish by energy absorbed directly by the fish greatly improved the drying efficiency. This method has found wide application in drying of fish. Solar dryer can depend on the natural convention or forced airflow convection. The forced convection dryer make use of electricity to drive a fan, which circulates air in the dryer. This has limited use in fishing villages where electricity may not be available. The commonly used solar dryer by fisher folks in the tropic is the natural convention type. Andrew (2001).

2.2.1 Natural Convection Solar Dryer

Andrew (2001) recorded the efficiency of natural convection Solar dryers made of plastic of glass. Generally, they have lower drying rate in the first phase of drying when the high humidity in the dryer retards the removal of moisture. In the second phase, a higher drying rate was obtained because of the higher temperature and lower humidity in the solar dryer in the phase.

Two types of nature convection solar dryers commonly used for drying of fish in the tropics are the solar- tent dryer and the Box-Type dryer.

2.2.2. **SOLAR TENT DRYER.**

Doe et al (1977) developed in Bangladesh, a simple dryer in form of a tent with frames of bamboo sticks or wood. The frame is covered with black or transparent plastic film (or both) to produce an enclosure with opening at the top and bottom

Fish is laid on racks inside the Solar Dryer. The black plastic film absorbs the heat energy from the sun while in the transparent type, the radiation comes directly into the tent and is absorbed by surfaces such as black Zinc, Black wood or black stone at the base. Cool air enters the dryer through the bottom opening, while the top opening allows the heated air to flow out after it had circulated around the fish. Figure 1 shows the Solar Tent dryer.

Comparison of the performance of three Solar dryers namely solar tent dryer, separate collector and drying chamber (SCD) and solar tent cabinet dryer shows very little difference in the overall drying rate. However, fish were successfully dried in the dryers between three days compared with five days when sun drying Trim and Curran (1983)

2.2.3 BOX- TYPE DRYER.

The box-type dryer is constructed with wooden frame with two glasses. The drying chamber is insulated with foam. Inside the chamber is black painted made of galvanized iron-sheets and a metal wire mesh to absorb heat. However, the occurrence of case hardening was noticed in some of the solar dried fish, which as attributed to the rapidly initial temperature during which resulted in the formation of a hard crust in the fish surface while the centre was still moist. Exposing fish to a lower drying temperature during the early stage by commencing drying in the morning hours when the temperature in the solar dryer was not properly controlled. Fig 2 shows a box type solar dryer

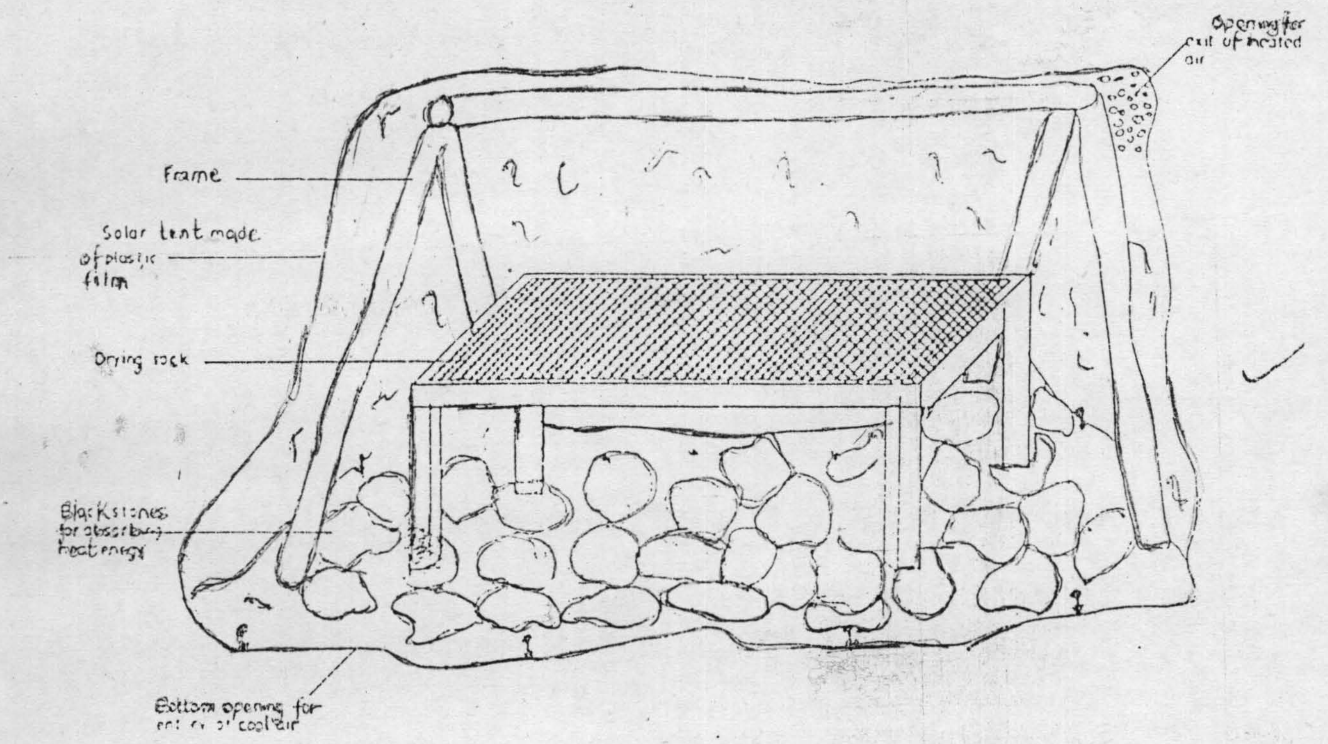


FIGURE 1: SOLAR TENT DRYER (ANDREW 2001).

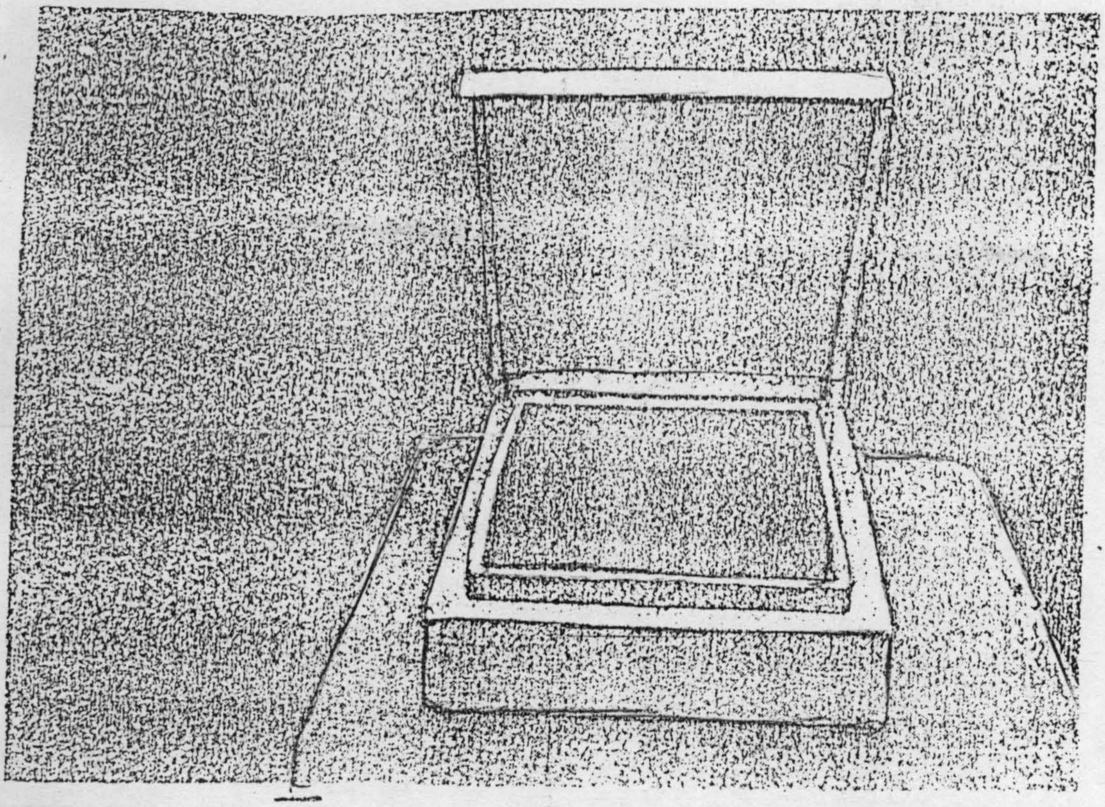


FIGURE 2: BOX TENT DRYER (ANDREW 2001)

2.3 TYPES OF ARTIFICIAL DRYERS

There are three mains types of artificial dryers: these are mechanical dryers, vacuum contact dryer and freeze dryers

2.3.1 Mechanical dryers

These dryers are designed to dry fish by the use of the heated air or by contact with heated surface. Electric heaters, stream, oil or hot water supplies heating. Movement of the air is aided by fan, which carry away moisture from the fish .One of the mechanical dryers, which is in use extensively in the fishing industry is the funnel or kiln .This is shown in fig 3

The general recommendation for artificial drying of salted lean the fish in the tunnel dryer in temperate countries is to exposes fish to temperature of 25-30^{0} air speed of 1.2 m/s and relative humidity of 45-55% in the dryer. Andrew (2001).With these air condition ,a tunnel dryer can successfully dry a highly salted fish from water content of 75% to 36% in 120hrs . The drying time could be reduced by pressing the fish gently at interval during process of mechanical press e.g rolker or plates. Pressing allow water to diffuse to the surface of the fish for evaporation in the dryer.

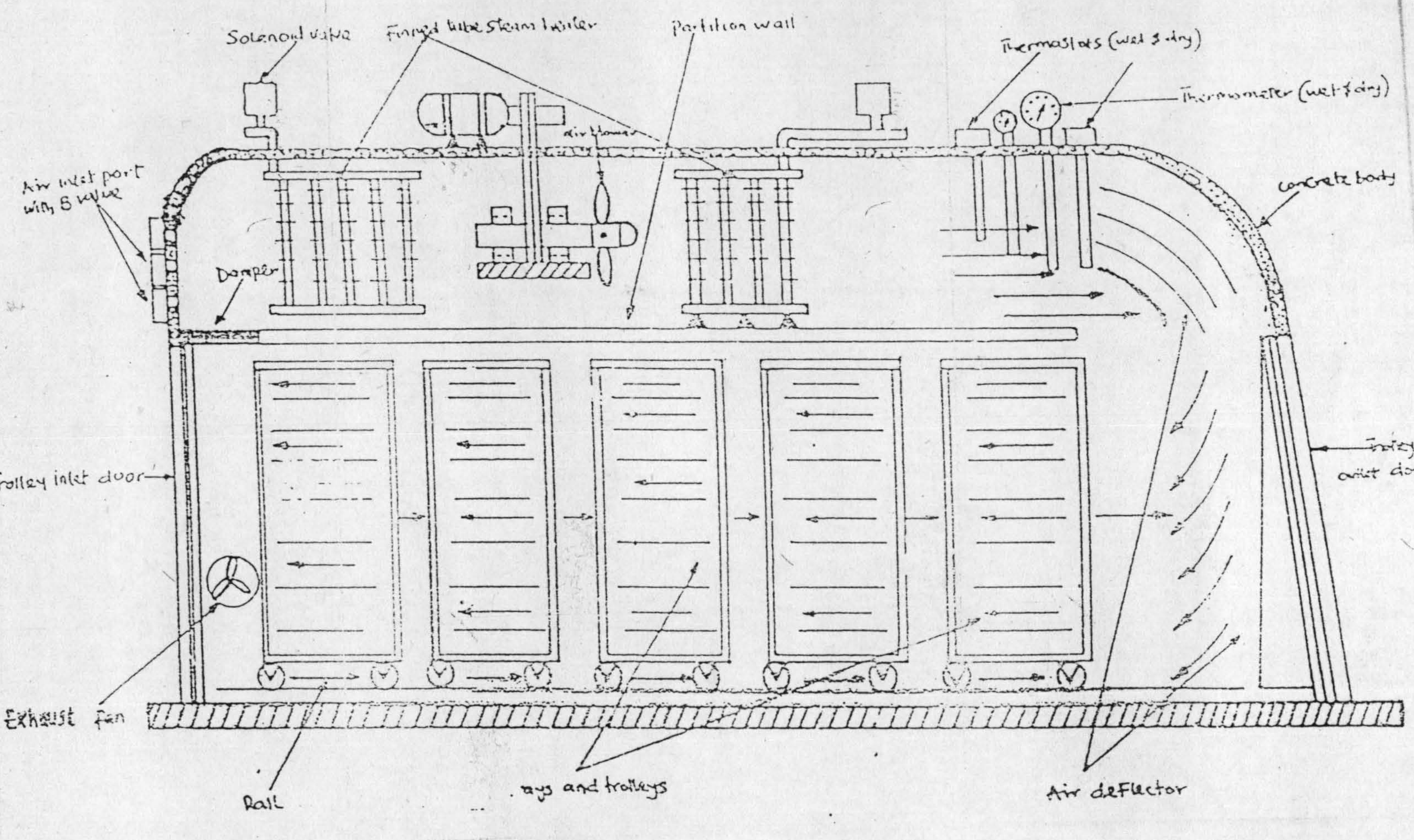


FIGURE 3: MECHANICAL DRYER (ANDREW 2001)

2.3.2 Vacuum Contact Dryer.

As the name implies, the vacuum contact Dryer operates by contact with heated plates in an evacuated chamber or by radiation followed by rapid evaporation of moisture with a vacuum pump, which keeps the fish cool. The absence of oxygen prevents oxidation of fat and oxidative rancidity.

The disadvantages of the vacuum contact dryer compared to the freezer dryer are:-

- Excessive shrinkage of fish
- Migration of dissolved constituents inside the fish to the surface causing case hardening i.e a hard impervious layer is formed which slows down both rates of rehydration and dehydration and reconstitution.
- Extensive denaturation of protein Andrew (2001)

2.3.3 Freezer dryer

The equipment is so called because the fish to be dried is first frozen and it remains frozen throughout the duration of the drying period. The rapid evaporation of moisture in the sealed chamber causes the fish to freeze as it dries. The water in the fish on freezing turns to ice crystals and these crystals are volatilized or "Sublimed" by heating the food at low pressure in a vacuum chamber. The water vapour then escapes from the food finally leaving at dry. A simple diagram of a freeze drying system with refrigerated condenser and mechanical vacuum pump is shown in figure 4.

Other Methods Of Drying

People have been drying fish for thousand of years back by placing the fish on mats or trays in the sun. This simple method, however, allows fish to be contaminated by dust, mould and fungi, insect, rodents and other animals this application has a wider application in the abundant rainfall and humidity are relatively low but the rate of drying is slow and the longer the drying under ambient condition and poorer the product quality.

Oven Drying

Basically there are two types of oven for drying fish namely

1. The Kerosene oven
2. The electric oven.

The kerosene oven makes of kerosene as a source of energy, while the electric oven makes use of electric power. Electric Oven is the most efficient of all the methods of fish drying but it is only applicable in the urban areas, and this is not used by our rural dwellers due to lack of electricity and the cost of acquiring the source of energy comparing the solar dryer with the drying oven method, one can easily conclude that it is cheaper to run since sun is easy to come by.

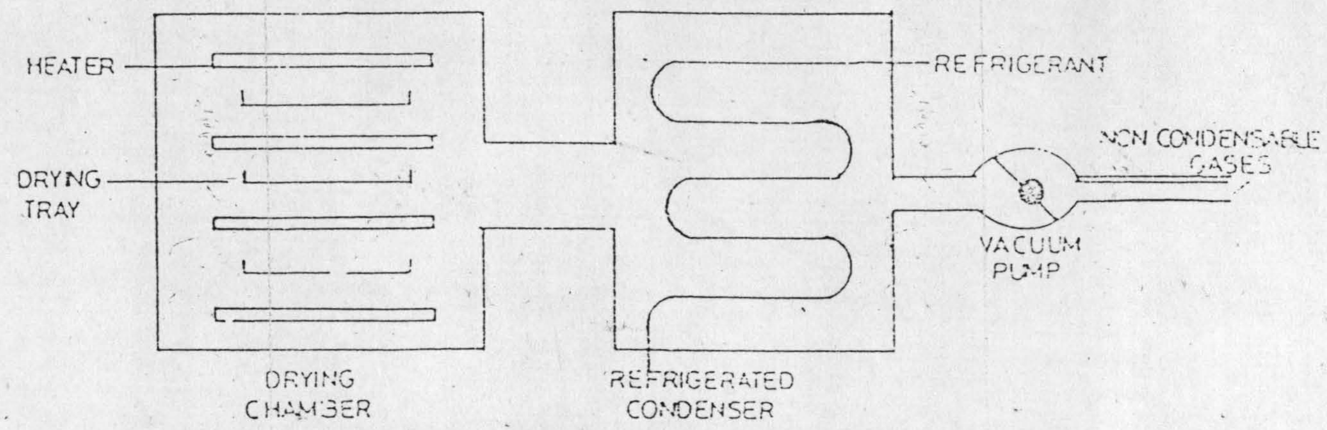


FIGURE 4: FREEZE DRYER SYSTEM (ANDREW 2001)

2.4 THE FISH DRYING PROCESS

During fish drying, moisture migrates to the surface of the fish fillets and then evaporates. Such water carries with it soluble substances such as sugar, phosphates and amino acids which are deposited on the surface of the product, this retarding the rate of evaporation, and setting a higher required heat input to effect evaporation. This results in thermal denaturation. As water migrates to the surface and is evaporated, the moisture content with in the product as well as the drying rate falls.

The falling moisture content within the product results in concentration of solution and a lowering if pH value. A combination of these results in extensive protein denaturation, which limits the re-hydration properties of the product and causes toughening in the re-hydrated products. In addition, the concentration of solubles in the outer coating of product causes enzymic browning which also limits rehydration properties of the product.

2.5 PRINCIPLE OF FISH DRYING

Preservation by drying is effected by lowing the water vapour pressure of the fish to a level which micro-organism can no longer grow. The ratio between the water vapour pressure of a substance and the vapour pressure of pure water at the same temperature is called water activity (aw). This ratio also expresses the relative humidity of air with which the substance is in equilibrium. Most micro organism can grow (aw) of 0.95 and above. Andrew (2001).

In order to destroy the micro-organisms enough heat must be applied on fish to reduce the water activity in the milieu. Heating not only reduces the water activity of the fish but also desiccates the micro organism causing them to die out. The destruction of micro-organisms during the drying process depends not only on the nature and level of infestation, but also on environmental factors such as relative humidity and the speed of air flow and particularly on the changes in temperature water content of the product.

2.6 SOLAR COLLECTORS

Solar collectors are employed to gain useful heat energy from the sun's radiation. They are almost invariably used to heat either air or water and may be either of the (concentrating) type or of the (non concentrating) flat plate type. Concentrating collectors use a specially shaped focusing reflector this increasing the intensity of radiation on the absorbing surface and can attain higher temperatures than flat plate air heating collectors can provide the desired temperature elevation and are a more appropriate solution than the more complex concentrating collectors Brenndorfor et al (1985)

2.6.1 Flat Plate Solar Collectors

The basic components of flat plate solar collectors are an absorbing surface which receives insolation and an air duct one side of which is formed by the absorber. Other elements which are frequently used in flat plate collectors are clear covers placed above the absorber to reduce heat loss from the absorber and insolation as shown in figure 5. For the many application where a relatively high air flow is required a fan is used to blow air in the collector.

2.7 ABSORBER PERFORMANCE

Factors affecting the amount of energy absorbed by the absorber plate are:-

(i) The levels of insolation; clearly the higher the insolation, the greater the energy absorbed. For this reason some knowledge of typical insolation level is borne in mind that insolation levels can very considerably from place to place and at difference times of year.

(ii) The angle between incident insolation and the absorber plate surface. Ideally, the absorber plate should be perpendicular to the insolation. As the angle of insolation varies with time of day and throughout the year this ideal condition cannot always be satisfied.

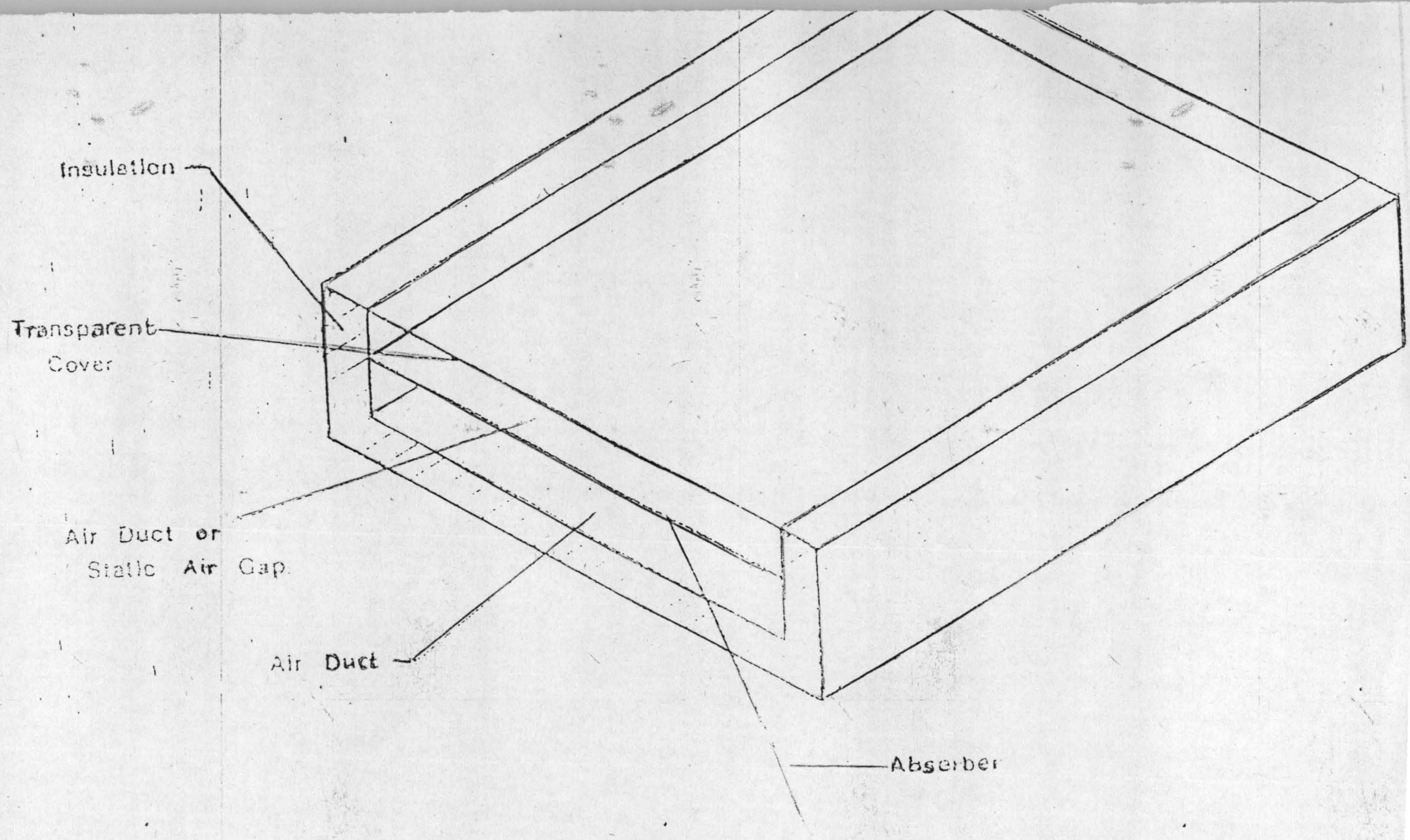


FIGURE 5: FLAT PLATE COLLECTOR (BRENNDERFER 1985)

(iii) The absorptivity of the absorber surface. The greater the absorptivity of the absorber surface, the higher the proportion of incident radiation that will be absorbed.

(iv) The transimissivity of the cover material (if a cover is used) one further type of flat plate collector worthy of mention is that with a porous, high surface area absorber (Macedo and Altemani (1978).

2.7.1 Absorber Materials

Desirable properties for the absorbers in solar collectors as recorded by Brenndorfer et al (1985).

(i) High absorptivity of incident radiation;

(ii) low emissivity

(iii) good thermal conductivity in the case where air flow is below the absorber;

(iv) stability at the temperature encountered during operation at the stagnant conditions.

(v) durability;

(vi) low cost;

(vii) low weight per unit area.

One of the more commonly used absorbers is black painted metal sheet, frequently this is corrugated galvanized iron. This has the advantages in most places of being rapidly available, relatively cheap and easy to use.

Other suitable absorber are black plastic sheet, painted rocks, ash and charcoal.

In the rare cases for drying purposes, when the required temperature elevation exceeds 40^0c the use of selective absorbers becomes more attractive. Selective absorber are materials which have a high absorptivity but also a low emissivity, much more so than material like black paint.

2.8 CLASSIFICATION OF SOLAR DRYER

Brenndorfer et al (1985) also recorded the classification of solar dryers based upon the following criteria:-

(i) Whether or not the drying commodity is exposed to insolation;

(ii) The mode of air flow through the dryer;

(iii) The temperature of the air circulated to the drying chamber.

2.8.1 Exposure to Insolation

Based upon this criteria solar dryers can be termed either direct or indirect. Direct dryers are termed those in which the crop is exposed to the sun and indirect dryers those in which the crop is placed in an enclosed drying chamber and thereby shielded from insolation. Indirect dryers heat transfer to the drying crop is by conventions and radiation and therefore the rate of drying can be greater than indirect dryers.

2.8.2 Mode of Air flow

There are two possible modes of airflow, natural convection or forced convection. The former is reliant upon thermally induced density gradients for the flow of air through the dryer whereas for forced convection dryers, the airflow is dependent upon pressure differentials generated by a fan. The later is obviously capable of providing a much greater airflow and therefore suitable, if not essential, for dryers with large throughout.

2.8.3 Circulated Air Temperature

The air entering the drying chamber of a solar dryer can either be at the ambient temperature or at some higher temperature; the elevation in temperature of the air being achieved by its passage through a solar collector prior to the drying chamber.

Dryers that employ a separate solar collector and drying chamber have an inherent tendency towards greater efficiency as both units can be designed for optimum efficiency of their respective functions. However, a dryer with a separate collector and drying chamber can be a relatively elaborate structure whereas the combined collector and drying chamber can be relatively simple and compact.

CHAPTER THREE

3.0 METHODOLOGY

3.1 DESIGN ANALYSIS

The size of dryer depends on the number of fish dried at any given time. This fish dryer will be designed for 40 fishes (tilapia) *Tilapia Zilli.* Therefore the main area that will be occupied by the fish will be subsequently determined. Table 1 shows the length, breath and the Area of 4 samples of fish (Tilapia) *Tilapia Zilli.*

Table 1: Physical Parameters of sample of Tilapia Fish.

Sample Number	Length (mm)	Breath (mm)	Area (mm^2)
1	150	60	9,000
2	170	75	12,750
3	140	65	9,100
4	200	80	16,000

Based on these values, the mean area occupied by a fish is:

$$\text{Mean area occupied by the fish} = \frac{900 + 12,\ 750,\ +9,100 + 16,000}{4}$$

$$= \frac{46,860}{4}$$

$$11,712.5mm^2$$

Therefore, the mean area occupied by a fish in 11,712.5mm^{2}.

Since the mean area occupied by a fish in 11,712.5mm^{2}, therefore the area occupied by 40 fishes will be.

11,712.5 x 40

= 468500mm^{2}.

To determine the total weight of fish dried at any given time. The weight of four sample of fresh fishes above were determined by using a weighing instrument.

Table 2. Weight four sample of fishes (Tilapia fish).

Sample Number	Weight (g)
1	75
2	90
3	65
4	100

$$\text{Average Weight} = \frac{75 + 90 + 65 + 100}{4}$$

$$= \frac{330}{4}$$

$$= 82.5g$$

Therefore, total weight that the rack (drying chamber) can accommodate is the product of the number of fishes occupied by the rack and the weight of the sample.

= (3300.0)g

$$= \frac{3300g}{1000}$$

= 3.3 kg.

So, the rack can accommodate approximately 3.2kg

3.2 SOLAR COLLECTOR

To maximize the level of insolation on a collector, the simplest approach is to situate the collector so that it is perpendicular to insolation at mid-day in the middle of the drying season. Brenndorfer et al(1985)

$\delta = 23.45 \sin [0.9863. (284 + n)]$ 3.0 Brenndorfer et al (1985)

The above formula given is the angle of declination δ

Where n = day number which varies from the first of January to 31st of December in a year.

The mid-point of the drying season is taken December 15. This is the approximate mid-point of the dry season in the Tropical region. Bamiro and Ideriah (1985)

For December 15, n = 349.

δ = 23.45 Sin [0.9863 (284 + 349)]

= 23.45 Sin (625)

= 23.45 (-0.996)

= -23.2^0

3.2.1 Determination of the intensity of Insolation on the collector surface.

Due to the limited amount of information available and the variation in intensity of insolation with climatic conditions, precise prediction of the intensity of insolation on the collector surface is not possible.

But daily insolation (global radiation) on the horizontal surface for various latitude in Nigeria as done Ezeilo (1985), Simonson (1984), Ezekwe (1983) and Oje and Osunde (1992), an interpolation was done for Minna to get the average hourly insolation as 825 W/m^o k. the altitude for Minna is 323 meters. In the above interpolation, average day-light was taken at 12 hours.

To calculate the angle of incidence for insolation for a horizontal surface Qh, since the slope angle is zero.

$\text{Cos } Qh = \text{Sin } \delta \text{ Sin } \phi + \text{Cos } \delta \text{ Cos } \phi \text{ Cos } \omega$ - 3 .1

ϕ = latitude value for Minna

ω = hour angle

δ = Calculated from equation 3.0

Therefore values for $\delta = -19.2^0$ on November 15

$= -23.2^0$ on December 15

$= -21.3^0$ on January 15

Estimated means values of Qh over day can be made by assuming a 12 hour day and dividing it into four 3 hour period and calculating Qh for each period.

To vary from 06.00hrs to 18.00hrs

From 06.00hrs to 09.00 hrs = -67.5^0

09.00hrs to 15.00 hrs = -22.5^0

12.00hrs to 15.00 hrs = -22.5^0

15.00hrs to 18.00hrs = -67.5^0

For December 15, for the period 09.00hrs to 12.00hrs, Cot Q = 0.937. According to the above researchers, daily radiation on a horizontal surface is approximately 19.20MJm^2 day $^{-1}$. Insolation on horizontal surface for the period 09.00 hrs 12.00hrs on December 15 is calculated thus.

Insolation (Ih) = 825w/m^2 for the period 09.00hrs – 12.00hrs

$\text{Cos } Q = \text{Sin } \delta \text{ Sin } \phi \text{ Cos } \beta$

$- \text{Sin } \delta \text{ Cos } \phi \text{ Sin } \beta \text{ Cos } \infty$

$+ \cos\delta \; \cos\phi \cos\beta \cos\omega$

$+ \cos\delta \sin\phi \sin\beta \cos\infty \cos\omega$

$+ \cos\delta \sin\beta \sin\infty \sin\omega$

latitude ∞ = surface azimuth angle.

Hour angle δ = Declination angle

β = slope angle

Cos Q = 0.780

Therefore, insolation intensity on the collector surface

$$Ic = 1h \cdot \frac{\cos Q}{\cos Qh} \quad \ldots\ldots\ldots 3.2$$

Cos Q for period 09.00hrs – 12.00 hrs = 0.937

Cos Qh for period 09.00hrs – 12.00hrs = 0.780

$$\text{Therefore} = \frac{\cos Q}{\cos Qh} = \frac{0.937}{0.780}$$

Ic = Ih x 1.201.

Where Ih = 825 w/m^2

Ic = 825 x 1.201

$\simeq$ 990 w/m^2

3.3 DETERMINATION OF THE COLLECTOR AREA

Brenndorfer et al (1985), Also stated expression for determination of collector area. In order to determine the collector area, the procedure is to first estimate the collection efficiency, then the collector area.

$$\eta_c = \frac{1}{1+U_L h} \cdot \left[1 - \exp\left(-\frac{U_0}{G_a} . C_p\right)\right] \frac{GaCp}{U_0} . f \qquad ....3.3$$

Where:

Uh = collector heat loss coefficient 6.99 $wm^{-2}\ k^{-1}$

h = heat transfer coefficient between absorber and flowing air

22.7 $wm^{-2}\ k^{-1}$

U_0 = overall heat transfer coefficient 5.3 $wm^{-2}\ k^{-1}$ (Assumed)

G_a = Mass flow rate per unit collector area 40.8 kg $5^1 + m''^2$

Cp = Specific heat of air 1005 kJ. Kg k^{-1}

f = effective transmissivity absorptivity product of cover and absorber.

The above values is obtained from appendix 2

Hence

$$\eta_c = \frac{1}{1+6.99 \times 22.9} \times \left(1 - \exp \frac{-5.3}{40.8 \times 1.005}\right) \times \frac{40.8 \times 1005}{5.3} \times 0.88$$

$$\eta_c = 0.765 \times 0.121 \times 7.737 \times 0.88$$

$$\eta_c = 0.63$$

Therefore the collector Area is

$$\eta_c = \frac{V.L.Cp\Delta T}{AcIc} \times 100\% \text{..............................} 3.4$$

$$Ac = \frac{V.L.Cp\Delta T}{\eta_c I_c} \times 100\%$$

Where:

AC = Collector Area in (m^2)

V = Volumetric flow rate of air (M^3S^-1) 1

∂ = Air density (Kg M^{-3}) 1.28 kg m^{-3}

DT = Air temperature elevation (°C) = 50°C

(Expected temperature in drying chamber)

Cp = Air specific heat (JKg^{-1} oC^{-1}) - 1 0Jkg ^{-1}C

ηc = Collection efficiency = 0.63

Ic = Isolation (w/m^2) = $990/m^2$ (Calculated in 3.2.1)

$$Ac = \frac{1 \times 1.28 \times 1.005 \times 110 \times 50}{0.63 \times 990}$$

$$= 1.031 m^2$$

The collector will be square surface in which the air-heating medium is above the absorber.

3.4 DETERMINATION OF THE COLLECTOR LOSS COEFFICIENT

(a) Heat loss "coefficient from the top. The major heat loss from the |

1 collector is from the top and the heat transfer coefficient for the top is given by:

$$\left[\frac{N}{(344/Tp)(Tp-Ta)/(N+F)}+\frac{1}{hw}\right]^{-1}$$ (Duffie and Beckman, 1974)

Also.

$$Ut=\frac{(Tp+Ta)(Tp^2+Ta^2)}{\left[CEp+0.0425N(1-Ep)^{-1}+(2N+F-1)Eg\right]^{-N}}$$

Where

Ut = loss coefficient

N = 1 (glass cover)

F = factor = (1 - 0.04hw + 5.0w - $4hw^2$) (1+ 0.058N)

hw = 3.7 + 3.8^V ; when v = 2.24 m/s^2

Ta = ambient temperature

Tp = drying temperature

Thus, substituting the value of hw^2; f and hw - 14.21 w/m°C

$$= \left[\frac{1}{\left(344/320.33\right)\left(320.33 - 303/1 + 0.563\right)^{0.31}} + \frac{1}{14.21} \right]^{-1}$$

$$= \left[\frac{5.67 \times 10^{-8}\left(320.33 + 303\right)\left(320.33^2 + 303^2\right)}{\left(0.86 + 0.0425(1 - 0.86)^{-1} + \left(2 + 0.563 - 1\right)/0.88^{-1}\right)} \right]$$

$$= 6.66N / m^{2}C$$

b. Heat loss coefficient from Back and Sides.

The loss coefficient from back and sides depends on-the thermal conductivity of the insulator material and the thickness of the insulation material. The insulation material chosen is polythene foam (rigid) with thermal conductivity

K =0.0245 W/M ^{0}C (Brennderfer et al,1985).

Heat loss from back is given as

$$\text{Uback} = \frac{K}{L}$$

$$\text{Uback} = \frac{0.0245}{0.05} = 0.49 w / m^{2\,0}C$$

where

K = thermal Conductivity L = thickness of Insulator (Back) (5cm) Uback

The side heat loss is taken to be negligible since insulation was. used.

UL = Ut + Uback + Uside
= 0.66+0.49+0
= 7.15w/m^{0}C

3.4.1 The Absorber Plate.

Galvanized sheet which is readily available will be used as the absorber, the absorber will be nailed to the wooden side. Availability of this material and the Cost was taken into consideration. Also, the absorber will be packed with foam insulation. The Insulator with 24Kglm^3 density and thermal conductivity of 0.0245 w/m^{0}C. will be used (Brennderfer et al,1985).

3.5 COLLECTOR'S DIMENSION

The collector is of conventional design in which the air heating medium absorber plate. (From the area occupied by 40 fishes) the collector surface area will be square.

Length = 0.8m

Breath = 0.8m

Height = 0.2m

Collector volume = 0.8 x 0.8 x 0.2

= 0.128m^3

Collector Cross sectional area = 0.8 x .0.2

= 0.16m^2

3.5.1 Drying Rack:-

From previous calculation the area occupied by 40 fishes (468500mm^2)

Therefore the length of the drying rack = 0.7m

Breath of the drying rack = 0 .7 m

Area = (0.7 x 0.7)

$= 0.49m^2$

Since the area occupied by the 40 fishes ($468500mm^2$) $0.469m^2$ is lesser than the drying rack. Therefore the fish (40pieces) can be dried on the drying rack.

The diagram of the drying chamber is shown in the figure 6 below.

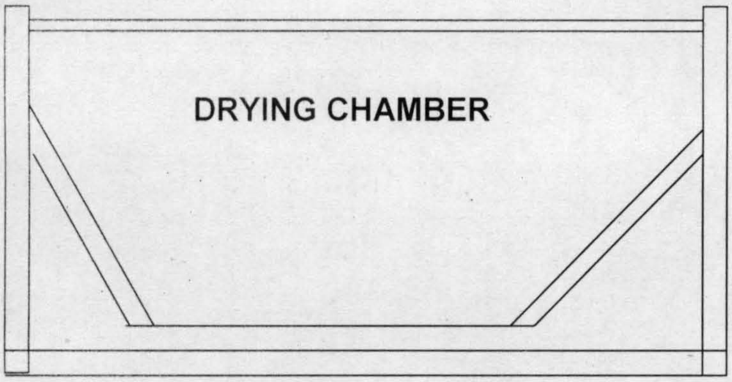


Figure 6 Drying Chamber.

3.5.2 The transparent cover

Transparent cover is incorporated to provide insolation at the top of the absorber plate or significantly, the short-wave solar radiation to absorber plate. Glass is commonly used because of its excellent weather ability and good mechanical properties. Glass has solar transmittance (87% - 92%) and can be very transparent if it has a low oxide content. It is opaque to longwave radiation and thus reduces radiation losses compared with plastics. Brenndorfer et al, (1985).

3.5.3 The passage / Channel

The heated air or liquid is being transferred from the solar collector through an open channel to the drying chamber.

3.5.4 The housing casing

This is made of seasoned wood, plywood nailed together to prevent heat losses.

Heat gain by the fish is equal to heat gain in the drying chamber and it ca be expressed by the first law of thermodynamics. Holman (1978).

$Q = MK\Delta T$ .... Holman (1978)

Where

Q = Quantity of heat required in (kg^0c)

M = Mass of air in the dryer

K = Specific heat capacity of air is 0.24kg/kg of dry air

ΔT = Temperature difference

Projected temperature in the drying chamber = 50^0 c, outside temperature (Ambient temperature) 35^0c

Therefore, mass of air in the dryer (M) can be calculated as follows

$M = D \times V$ (Kg) 3.3

Where D = density of air which is 1.2 kg/m^3 (Holman 1978)

V = Volume of the drying chamber in M^3

= $0.128m^3$ (Collector's dimension)

M = (1.2 x 0.128) kg

= 0.154kg

Mass of air in the drying chamber = 0.154kg

Hence,

Q = 0.154 x 0.24 x15

= $0.554kg^0C$

Therefore, the quantity of heat gin in the drying chamber is $0.554kg^0C$.

3.6 MODE OF OPERATION

The solar fish dryer absorb solar radiation with minimum or no reflection. The collector consist of a galvanised sheets with a glass cover. The collector is developed in such a way that is detachable from the other body (drying chamber)

The fish is kept and arranged on the rack (wire gauze) in which water easily drains outs of the fish. The heated air in these in the collector passes within the drying chamber by convective means and the moisture is removed from the fish.

The access to the drying chamber enhances easy loading and unloading of the fishes on the rack and provide means to control the temperature in the drying chamber. The fish in the dry chamber can be dried with in limited period because the fish are placed above the galvanished sheet (black).

CHAPTER FOUR

4.0 TEST EVALUATION AND DISCUSSION

A type of sample fish was used (Tilapia) for the performance test of the dryer. Tests on drying were carried out using Tilapia fish. Fish were weighed and put in the drying rack. The changes in weight at a time interval of 2 hours were recorded. An open air sun drying was also carried out as a control, while change in weight were recorded simultaneously with ones in the drying rack.

The ambient and the drying chamber were recorded at the same time for weight recording.

TEST RESULT

Table 3 and 4 gives the weight of fishes tested, the moisture removed every two hours interval.

Table 3 : weight of fish in the solar dryer at two-hour interval

Type of fish (Tilapia)	Initial weight	2hrs	4hrs	6hrs	8hrs	10hrs	12hrs
Temperature °C	7.00hrs 40	9.00hrs 38	11.00hrs 56	13.00hrs 58	15.00 49	17.00hrs 47	19.00hrs 40^{0}C
Weight (g)	3100	1860	1525.2	1010.6	912.0	912.0	912.0

Table 4: Weight of fish in sun drying at two-hours interval

pes of fish apia	Initial weight	2hrs	4hrs	6hrs	8hrs	10hrs	12hrs	14hrs	16hrs
mperature ^{0}C	7hrs 32	9hrs 33	11hrs 35	13hrs 35.5	15hrs 35	17hrs 37	19hrs 37	7hrs 32.5	9hrs 33
ight (g)	3100	2150	1720	1501.8	1291.5	1124.7	1012.0	1012.0	1012.0

4.1 CALCULATIONS AND RESULT

To calculate the moisture content at each interval, the following expression was used (solar dryer) from table 3 and 4.

$$MC = \left[\frac{(W - W_2)}{W1} \times 100 \right] \ldots\ldots 4.1$$

MC = Moisture content

W_1 = initial weight

W_2 = Final weight

Determination of moisture content of the fish (solar dryer)

MC at 2hrs (9.00hrs)

$$\frac{3100 - 1860}{3100} \times 100 = 11.9\%$$

MC at 4 hrs (11.00hrs)

$$\frac{1860 - 1525.2}{1860} \times 100 = 10.8\%$$

MC at 6 hrs (13.00 hrs)

$$\frac{1525.2 - 1340.6}{1525.2} \times 100 = 12.1\%$$

MC at 8hrs (15.00hrs)

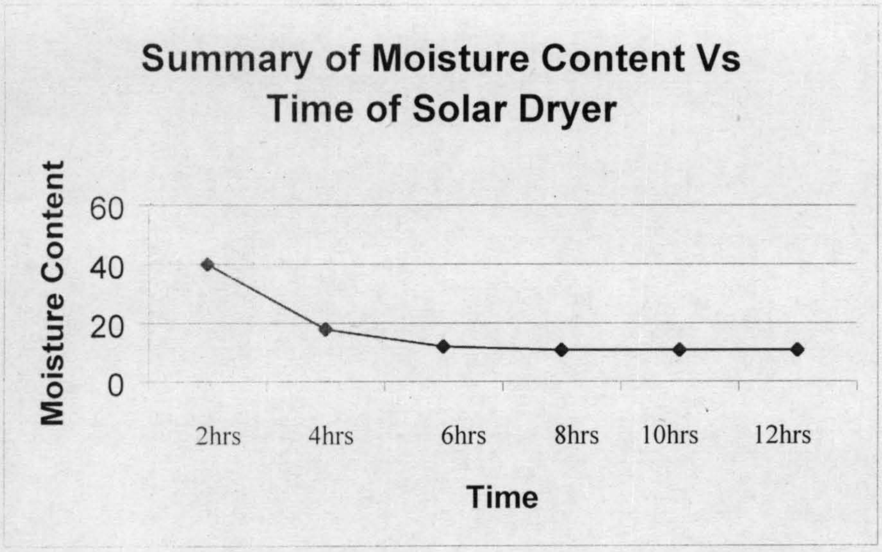
$$\frac{1340.6 - 1195.8}{1340.6} \times 100 = 10.8\%$$

After 15.00hrs, the other two interval recorded a consistent weight. Therefore the moisture content was recorded as 10.8%.

Table 5:- Summary of Moisture content Vs Time of solar Dryer

Time	2hrs	4hrs	6hrs	8hrs	10hrs	12hrs
Moisture content %	40	18	12.1	10.8	10.8	10.8

GRAPH 1



Determination of moisture content of fish in sun drying method

MC at 2hrs (9.00hrs)

3100 – 2150 x 100 = 30.6%

MC at 4hrs

$$MC = \frac{2150 - 1820}{2150} \times 100 = 20\%$$

MC at 6hrs

$$MC\ \frac{1820 - 1501.8}{1820} \times 100 = 18.5\ \%$$

MC at 8 hrs

$$MC\ \frac{1501\ .8 - 1291.5}{1561.8} \times 100 \quad = 15.0\%$$

at 10 hrs

$$MC\ = \frac{1291.5 - 1124.7}{12914.7} \times 100 = 14\%$$

At 12hrs

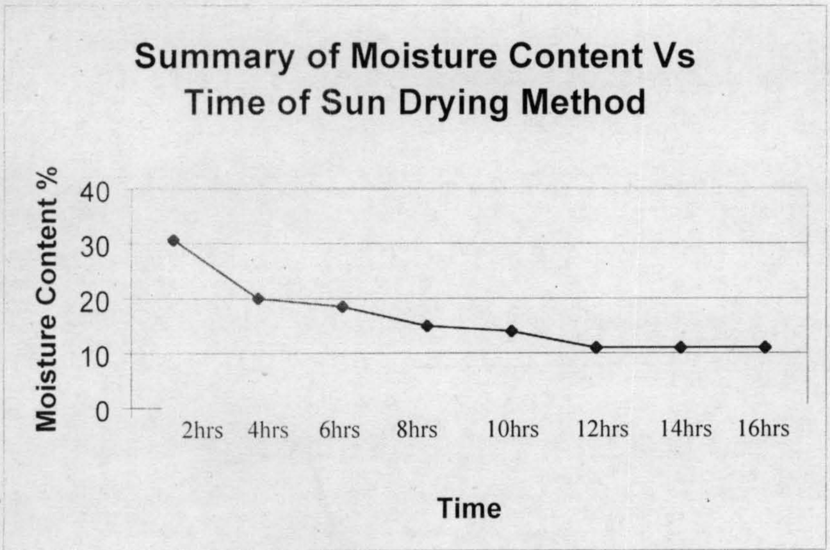
$$MC\ \frac{1124.7 - 1012.0}{11241.7} \times 100 = 11\%$$

At 12 hrs, 14hrs & 16hrs are observed to have consistent weight as 11%

Table 6:- Summary of moisture Content Vs Time of Sun drying Method.

Time	2hrs	4hrs	6hrs	8hrs	10hrs	12hrs	14hrs	16hrs
Moisture content %	30.6	20.0	18.5	15.0	14.0	11.0	11.0	11.0

GRAPH 2



4.2 DISCUSSION

On the graphs, it could be seen that the solar dryer dries faster and at a shorter time than the convectional sun-drying. The sun drying exceed 2hrs than the solar dryer to dry the fish.

Therefore, the soar dryer developed in better than the conventional sun – drying

During the drying test, it could be seen, that the sun-drying exceed to the second day to finish drying. The pick-up rate of the dryer is determined in Appendix IV.

The temperature obtained in the drying chamber of the solar dryer was found to be above 50^0C which in above the ambient temperature by about 15^0C; when the fish were arranged on the drying rack, it was observed fish were arranged on the drying rack, it was observed the temperature reduced from 40^0C to 38^0C which shows that the moisture is being removed from the fish. Gradually the temperature rose again. From the test, it was observed that the rate at which moisture was removed from the fish in the solar dryer was better than sun drying.

It can be seen that the fish under sun – drying had maggot on it due to the access to house flies where as the fish under solar dryer remains dried without any maggot (more hygienic)

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Conclusively, comparison of the two drying methods, investigated can be based on three criteria.

(1) Drying Rates

(2) Final moisture content

(3) Product Quality

DRYING RATE :- It can be seen, that, the drying rate of the solar dryer is faster than that of sun drying method. This could be seen in the test shown before.

FINAL MOISTURE CONTENT:- The reduction in the moisture content possible by drying is the solar dryer was consistently greater than that obtained by sun drying.

PRODUCT QUALITY:- It was considered that fish in the solar dryer were almost without exception, of very high quality. However for the fish dried in the sun-drying method, health hazard is possible due to flies, dust e.t.c which was not noticed in solar dryer.

5.2 RECOMMENDATIONS

Considering fish drying, it is clear that use of solar energy in drying food such as fish with high moisture content yield result comparable to that obtained, using conventional process of sun-drying. It reveals that with further work in the optimization of drier design for specific food items the use of solar energy will be better suited for drying purposes and the duration of drying would be shortened.

Finally, it is advisable to intensify efforts in developing simple solar dryer in the remote parts of the country, particularly since the country has a high potential in the use of solar energy in the drying industry.

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APPENDIX 1

Estimated daily mean solar Radiation for Minna

Month	Hm (MJ/M^3/day	1c (W/m)
January	21	743.83
February	24	800.03
March	24	856.82
April	24.50	879.64
May	22	870.54
June	21	853.44
July	19.5	854.99
August	20	865.48
September	19.0	852.35
October	18.50	829.08
November	20.50	770.71
December	19.20	726.42
Mean		$\frac{9903.33}{12}$ = 825.277w/m^2

Source : Osunde and Oje 1992

APPENDIX II

DATA FOR PREDICTION OF COLLECTOR PERFORMANCE

	f	U_L	U_O	U_O / GC_P
No cover	0.9	22.2	11.2	1.274
Single cover glass (k=0.2)	0.88	6.99	5.3	0.131
Single cover glass (k=0.6)	0.83	6.99	5.3	0.131
Single Tedlar cover	0.82	8.12	6.0	k0.146
Double cover glass (k=0.2)	0.78	4.43	3.7	0.91
Double cover glass (k=0.6)	0.74	4.43	3.7	0.091
Double cover one glass (k=0.2) over 1 Tedlar	0.79	5.25	4.3	0.103
Double cover Tedlar	0.84	5.44	4.4	0.107

(WILLIER, (1964)

Some assumption have been made in determining these values: these are:-

i. Air flow rate = 40.8 x 10^{-3} kg m^{-2} S^{-1}.

ii. Heat transfer coefficient h = 22.7 W M^{-2} k^{-1}.

iii. Rear and edge heat losses are 10% of upward heat loss

iv. Glass thickness = 2.5mm, Tedler thickness = 0.1 mm

v. Absorptivity of absorber = 0.95

vi. f is taken as 0.85 of the effective transmissivity- absorptivity product at normal incidence

vii. sky temperature taken as approximately 5^0C below ambient, wind speed 5mph (2.210^{-3} m S^{-1})

APPENDIX III

Determination of Average Temperature of the fish dryer and the Ambient Temperature for 4 days 9.00hrs. – 18.00hrs.

/03/2005	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	Average
nbient	31	33	35	36	36.5	32	32	37	38	38	34.9
yer T°C	40	42.5	56	70	67	60	50	49	47	44	52.6
/03/05	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	
nbient T° C	30	33	35	35.5	35	37	37	36	36.5	37	35.2
yer T°C	41	45	60	71.5	70	61	60	55	52	43	55.9
/03/05	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	
nbient T°C	26	30	32	36	36	37	36	36	35	35	30.6
yer T°C	38	50	59	69	63	62	53	52	48	43	59.6
/03/05	9.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	
nbient T°C	31	33	34	36	36	36	37	37	36.5	36	35.3
yer T°C	40	42	53	71	67	70	50	50	471	43	53.3

Average Ambient temperature (4days)

$$\frac{34.9 + 35.2 + 30.6 + 35.4}{4} = 34^{o}C$$

Average Dryer's temperature (4 days)

$$\frac{52.6 + 55.9 + 59.6 + 53.3}{4} = 55.4^{0}C$$

Therefore, the average temperature for the 4 days is 34°C (Ambient temperature) and 55.4^{0} C (Fish dryer temperature)

APPENDIX IV.

DETERMINATION OF THE AVERAGE PICK-UP RATE OF THE SOLAR FISH DRYER.

Average pick-up of the dryer: This is the average pick-up of moisture per hour over the entire drying time. This can be determined from this expression.

$$Qs = \frac{Mi - (Mcf - Mci)}{(100 - Mci).td} \qquad (Brennderfor\ et\ al\ 1985)$$

where: Mi = Mass of the fresh product (kg) (3100g)

Mci = Fresh product moisture content given by the "product data sheet". (75%)

Mcf = Final Moisture content of dried product (10.8%)

td = drying time (12 hrs)

Qs = Average pick-up rate of the dryer (kg/hr).

Therefore

$$Qs = \frac{3.1 - (75 - 10.8)}{(100 - 10.8) \times 12} \qquad \frac{3.1 - 64.2}{89.2 \times 12} \qquad = 0.186\text{kg/hr.}$$