# DEVELOPMENT AND PERFORMANCE EVALUATION OF AN ON-FARM FORCED CONVECTION SOLAR DRYER FOR TOMATO

**BY**

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# DECLARATION

**I declare that the work in this thesis entitle 'Development and performance evaluation of an on-farm forced convection solar dryer for tomato' has been performed by me in the Department of Agricultural Engineering under the supervision of Dr. A.M.I EL-Okene and Dr. D.D. Yusuf.**

**The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university.**

**Abdullahi, Aminu Fagge**

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|---|---|---|
| **Name of Student** | **Signature** | **Date** |

# DEDICATION

**I dedicate this work to my late parents, Alh. Abdullahi Umar and Hajia Rabi with profound affection and gratitude for the good foundation they have laid for my academic life. May the All Mighty Allah forgive all their sins and grant them paradise. Amin**

# CERTIFICATION

**This project thesis entitled "DEVELOPMENT AND PERFORMANCE EVALUATION OF AN ON-FARM FORCED CONVECTION SOLAR DRYER FOR TOMATO" by Aminu Abdullahi Fagge meets the regulation governing the award of the degree of Master of Science (Agricultural Engineering) of Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.**

| | |
|---|---|
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# ABSTRACT

An on-farm research to evaluate the performance of a forced convection tomato solar dryer at Kwanar Gafan tomato market in Kano State was conducted.

The dryer was built using mud blocks, white transparent polythene as dryer top cover and the drying trays made from traditional straw mat (*Asabari*).

The dryer with a capacity of 400kg (10 baskets) of fresh tomatoes was tested under 3 different drying methods (Forced convection, Natural convection closed chamber and Natural convection open chamber).

The results show that tomato was dried in 2 days and 4 days for Eke's and Local slice respectively as against 4 days and 8 days in open-sun drying.

Fifty percent saving in drying time was achieved for 2 different tomato slice types (Local and Eke's slice) under the forced convection solar dryer when compared with the traditional open sun dryer.

The drying rate of tomato under the forced convection solar dryer was significant ($P \leq 0.05$) from the other drying methods. There was also a significant variation ($P \leq 0.05$) in drying tomatoes within the drying chamber of the forced convection solar dryer for both local and Eke's tomato slice type.

The system drying efficiency of the forced convection solar dryer was 31%, which was higher than the other drying methods.

The organoleptic quality test of the dried tomato samples showed that samples in the forced convection solar dryer retained their attractive red colour similar to fresh tomato indicating no mould growth and tasted more like fresh tomatoes.

While samples of tomato dried under natural convection dryers show signed of mould growth and the colour changes to black.

# TABLE OF CONTENTS

**TITLE PAGE.....i**

**DECLARATION.....ii**

**DEDICATION.....iii**

**CERTIFICATION.....iv**

**ACKNOWLEDGEMENT.....v**

**ABSTRACT.....vi**

**TABLE OF CONTENTS.....vii**

**LIST OF TABLES.....x**

**LIST OF FIGURES.....xi**

**LIST OF PLATES.....xii**

**LIST OF APPENDICES.....xiii**

**TERMINOLOGY.....xiv**

**CHAPTER ONE INTRODUCTION**

**1.1 Introduction.....1**

**1.2 Statement of Problems.....2**

**1.3 Justification of the Study.....4**

**1.4 Objectives of the study.....5**

**CHAPTER TWO LITERATURE REVIEW**

**2.1 Introduction.....6**

**2.2 Previous Experimental Work on Solar Drying.....7**

**2.3 Configuration of Solar Dryers.....10**

**2.4 Theoretical Analysis of Flat-plate Solar Collector..... ...11**

**2.4.1 Basic Flat-plate Energy Balance Equation.....12**

2.4.2 Collector Efficiency.....14
2.4.3 Free Convectional Heat Transfer in Solar Collectors.....15
2.4.4 Flow Due to Wind.....19
2.5 Crop Drying Theory.....20
2.6 Fan Performance.....29
2.7 Drying Efficiencies.....34
2.7.1 System Drying Efficiency.....35
2.7.2 Collection Efficiency.....35
2.7.3 Pick-up Efficiency.....36
2.8 Tomato Production in Nigeria.....37
2.8.1 Introduction.....37
2.8.2 Tomato Production System and Zones.....37
2.8.3 Processing and Storage in Nigeria.....40
2.8.4 Drying Areas of Tomato in Nigeria.....40
2.9 Quality Test of Food.....41

CHAPTER THREE METHODOLOGY

3.1 Introduction.....42
3.2 Preliminary Survey.....42
3.3 Conceptualization of Dryer Configuration.....44
3.4 Design Considerations.....44
3.4.1 Determination of Dryer Capacity.....45
3.4.2 Determination of Quantity of Water to be Removed.....45
3.4.3 Determination of Collector Useful Energy Gain.....46
3.4.4 Determination of Theoretical Drying Period.....48
3.4.5 Determination of Air Flow rate.....49
3.4.6 Determination of Fan Shaft Diameter.....51
3.4.7 Determination of Fan Efficiency.....52
3.5 Selection of Construction Materials.....53
3.6 Construction of the Dryer.....53
3.7 Experimental Design.....56

3.8 Test Procedure……56
3.9 Instrumentation and Data Collection……60
3.10 Organoleptic Test……62
3.10.1 Colour Test……62
3.10.2 Flavour Test……62

CHAPTER FOUR RESULTS AND DISCUSSION
4.1 Introduction……63
4.2 Preliminary Investigation……63
4.3 Centrifugal Fan Evaluation……68
4.4 Cutting Time of Tomato Slice ……68
4.5 Result of Evaluation of On-site Dryers……69
4.5.1 Effect of Tomato Slice Type and Drying Method on Drying Period……69
4.5.2 Effect of Drying Tray Distance from Blower on Drying Rate in Forced Convection Solar Dryer……70
4.5.3 Effect of Drying Tray Distance from inlet on Drying Rate of Tomato in Natural Convection Closed Chamber Solar Dryer……74
4.6 Determination of Dryer Efficiencies……78
4.6.1 System Drying Efficiencies……78
4.6.2 Collection Efficiencies……80
4.6.3 Pick-up Efficiencies……81
4.7 Organoleptic Test……83
4.8 Cost Analysis ……84

CHAPTER FIVE CONCLUSIONS AND RECOMMENDATIONS
5.1 Conclusions……85
5.2 Recommendations……86
6 REFERENCES……87
7 APPENDICES……94

# LIST OF TABLES

**PAGE**


TABLE 2.1 Production by smallholder farmers for tomato in Nigeria. 39

TABLE 4.1 Production of tomato and hectares of cultivation for the dry season under Kadawa river project. 66

TABLE 4.1 Result of centrifugal fan evaluation. 68

TABLE 4.3 Summary of the result of drying local and Eke's sliced tomato under the four different drying methods 69

TABLE 4.4 Analysis of variance (ANOVA) of the effect of drying trays distance of local sliced tomato on drying rate in Forced convection solar and Open sun driers. 72

TABLE 4.5 Analysis of variance (ANOVA) of the effect of drying trays distance of Eke's sliced tomatoes on the drying rate in Forced convection solar and Open sun driers. 73

TABLE 4.6 Analysis of variance (ANOVA) of the effect of positioning of local sliced tomatoes in natural convection (closed chamber) solar and open sun driers. 76

TABLE 4.7 Analysis of variance (ANOVA) of the effect of positioning of Eke's sliced tomatoes in natural convection (closed chamber) solar and open sun driers. 76

TABLE 4.8 System drying efficiencies of tomatoes solar dryers. 79

TABLE4.9 Organoleptic Quality Test 83

# LIST OF FIGURES


| | | PAGE |
|---|---|---|
| FIGURE 2.1 | Forces on fan blade | 31 |
| FIGURE 3.1 | Sketch of conceptualized forced convection solar dryer. | 44 |
| FIGURE 3.2 | Engineering drawing of the forced convection solar dryer | 55 |
| FIGURE 3.3 | Sketch of arrangement of drying trays inside drying chamber. | 56 |
| FIGURE 3.4 | Sketch of tomato showing the major and minor diameters | 57 |
| FIGURE 4.1 | Drying rate curves of local sliced tomatoes in forced convection solar and open sun solar dryers. | 71 |
| FIGURE 4.2 | Drying rate curves of Eke's sliced tomatoes in forced convection solar and open sun solar dryers. | 72 |
| FIGURE 4.3 | Drying rate curves of local sliced tomatoes in natural convection (closed chamber) solar and open sun solar dryers. | 74 |
| FIGURE 4.4 | Drying rate curves of Eke's sliced tomatoes in natural convection (Closed chamber) solar and open sun solar dryers. | 75 |
| FIGURE 4.5 | Drying rate curves of local sliced tomatoes in natural convection (Open chamber) solar and open sun solar dryers. | |

# LIST OF PLATES


| | | PAGE |
|---|---|---|
| PLATE 3.1 | Constructed drying chamber. | 55 |
| PLATE 3.2 | Constructed drying chamber filled with sand | 55 |
| PLATE 3.3 | Samples of sliced tomatoes spread on the drying trays in drying Chamber. | 57 |
| PLATE 3.4 | Blower (fan) with diesel engine connected to the drying chamber. | 58 |
| PLATE 3.5 | Forced convection solar dryer loaded with samples of tomatoes and covered with polythene during test. | 58 |
| PLATE 3.6 | Haeni solar 118 delta instrument. | 61 |
| PLATE 3.7 | Dry bulb-Wet bulb thermometer (left) and Anemometer (right) Instruments. | 61 |
| PLATE 4.1 | Sliced tomatoes spread on the ground by the farmers for open Sun drying. | 67 |
| PLATE 4.2 | Professional dryers seen spreading and packing some dried tomatoes. | 67 |

# LIST OF APPENDICES


| | | PAGE |
|---|---|---|
| APPENDIX A (A-1, A-2): | Sample of Questionnaires utilized for Preliminary Investigation | 94 |
| APPENDIX B-1: | Detailed Tabulated Drying Performance Data of Forced Convection Solar Dryer for Tomato | 96 |
| APPENDIX B-2: | Detailed Tabulated Drying Performance Data of Natural Convection (closed chamber) Solar Dryer for Tomato | 97 |
| APPENDIX B-3: | Detailed Tabulated Drying Performance Data of Natural Convection (Open chamber) Solar Dryer for Tomato | 98 |
| APPENDIX C: | Detailed Material Cost Estimate of the Forced Convection Solar Dryer for Tomato | 99 |
| APPENDIX D: | Nutrient Composition of Canned, Red ripe and Sun Dried Tomatoes. | 100 |
| APPENDIX E: | Moisture Content (Oven dry method) of Fresh Tomato. | 101 |
| APPENDIX F: | Physical Properties of Tomato. | 102 |

# TERMINOLOGY

Eke's slice is a term used to describe a tomato slice type where the tomato is cut along its major axis in about 10 to 15mm thickness. The name was given after one of the researchers on tomato drying in the department of Agric. Engineering ABU Zaria.

Local slice is a term used to describe a tomato slice type where the tomato is cut into two, the way the farmers cut it before drying.

*Kauda* is a term used by the tomato farmers in the study area to describe a tomato when it is fresh.

*Bage* is a term used by the tomato farmers in the study area to describe spoiled or rotten tomato.

*Asabari* is a material of stems of long dried and thin grass, which is used traditionally to make mats that are used as door blinds mostly in the northern part of Nigeria.

*Dan kasa* is a term used by the tomato farmers in the study area to describe the local variety of tomato.

Forced convection solar dryer; this describes a solar dryer where polythene was used as top cover for the drying chamber and a blower (Fan) was incorporated in order to speed up drying of tomato.

Natural convection (closed chamber) solar dryer; this describes a solar dryer where polythene was used as top cover for the drying chamber but no blower (Fan) was incorporated.

Natural convection (open chamber) solar dryer; this describes a solar dryer where the chamber was open without any top cover, and also no blower (Fan) was incorporated.

# CHAPTER ONE

## 1.1 INTRODUCTION

Solar energy is becoming an important alternative source of energy. It is a source of energy that is abundant, inexhaustible, renewable and non-polluting. It can be tapped at relatively low cost and poses no environmental danger. Therefore, the use and application of solar energy cannot be overemphasized. The energy resource for agricultural application is strongly dependent upon the development of solar energy systems that have optimum performance, good reliability and economic characteristics that compare favourably with conventional energy systems and other energy sources (Ahmad and Abdul, 1997). This development must reach a point where satisfactory thermal performance and reliability can be achieved for numerous solar energy applications. Also to be economical, solar energy systems must have high continuous utilization and relatively long life and must be properly designed for location and application. Therefore, it is important to consider the amount of solar radiation available for the area, the location and the nature of the specific application to realistically evaluate solar energy as an alternate energy source (Bassey, 1989).

Drying is the removal of water from a substance through the application of some energy source. This could be in the form of direct solar energy, energy from burning fossil fuel or the energy stored in a moving air stream by first allowing it to pass

through a desiccant in order to reduce its relative humidity. Drying of agricultural product is more convenient to handle and less energy demanding than preservation by cold storage (Awachie, 1989).

In sub-Saharan northern parts of Nigeria, where there is high intensity of sunshine and low relative humidity in most part of the year, grain crops are normally left to dry naturally in the field before final harvest. Some early maturing crops in sub-Saharan region need supplemental heating of the drying air for effective drying of crops to safe storage conditions.

Vegetable crops such as tomatoes, okra, onions and pepper are perishable crops and are generally grown and widely eaten in Nigeria. They are characterized by being in good quality, excessive and cheap in their seasons and scarce, costly and in bad quality out of seasons. Keeping these crops for some months in their fresh state (such as to retain the actual nutrients, taste and colours as when freshly harvested) has remained a problem yet unsolved, because they deteriorate few days after harvest (Aliyu and Sambo, 1993). Peterson (1977) had estimated that 60% of tomato produced in the third world countries rot away annually. These losses give rise to short supply and high price during the off seasons.

## 1.2 Statement of Problems

In many tropical and sub-tropical regions, sun drying remains the preferred method of drying agricultural products, mostly for economic reasons (Bakker-Arkema et al., 1999). Over 90% of agricultural products are sun dried in Nigeria and in most other African countries (Arinze et al., 1990). This frequently, results in poorly dried and

infested products since drying under the sun is subject to contamination by dust, micro-organisms, insect, birds, animals and consequently spoilage and quality deterioration.

In most developing countries there is an increased emphasis on rural development, which undoubtedly will necessitate increase energy demands in the rural areas. The use of solar dryers for drying agricultural produce in both rural and urban areas will no doubt become important in the sense that cheap and only non-depletable (renewable) energy source such as solar and wind will be common place unlike electricity or wood powered drying systems. Eke et al. (1995) showed that over 50% saving in drying time could be achieved with cheaply constructed solar dryers when compared with open sun drying method. Nutrient quality, microbial load and colour change were also shown to be tremendously improved under solar dryer.

In Nigeria, the rural farmers constitute about 80% of the entire population and they are responsible for about 90% of the country's agricultural output (Omoregie, 1989).

The rural areas lack electricity and thus the rural farmers face serious problems of storage and preservation during harvesting periods, particularly, at seasons of increased yield.

Fruit and vegetable production is very high in many African countries. Unfortunately large quantities become spoilt due to the inexistence of adequate post-harvest facilities, inadequate transportation facilities, refrigeration systems are generally not available due to high capital cost and lack of reliable electricity supply, traditional sun drying generally does not give products of acceptable nutritional quality (Onwuka et al., 2002).

Open-sun drying is still the most widely practised agricultural processing operation in the world. The Food and Agriculture Organisation (FAO) stated that in 1968, 255 million tonnes of agricultural produce were dehydrated by open-sun drying (Brenndorfer et al., 1987).

## 1.3 Justification of the Study

There has been a demand for artificial dryers because of the ever increasing labour cost, the demand for improved quality of product and sometimes uncertain climatic condition. These dryers can generate high air temperatures and consequently lower the relative humidity, which improved drying rates and lower final moisture content of the dried crop (Bassey, 1989). Additionally, drying in an enclosed structure enhances protection against insect and other animals.

Different types of tomato dryer were designed and constructed at different times in the department of agricultural engineering ABU Zaria by Akani (1990), Eke (1991), Aliyu (2000) and Daniel (2004) among others. The problems of some of these dryers was that, assessment of the relationship between the farmers' production i.e. quantities of tomato dried at a given time and capacity of the dryer constructed was not considered, also most of the dryers were more or less laboratory types rather than the on-farm types where the farmers can see how it is being constructed and tested. Therefore there is the need to design a dryer that would cater for the quantity of tomato that the farmers need to dry at a given time and also to be more effective than their method of drying.

## 1.4 Objectives of the Study

The objectives of this study were:

(i) To undertake an assessment of existing methods of tomato drying by farmers in the villages around the study area.

(ii) To design and construct a large size, on-farm forced convection solar tomato dryer using locally available materials that are commonlly found in the study area.

(iii) To evaluate the performance of the forced convection tomato solar dryer.

(iv) To compare the performance of the forced convection tomato solar dryer with open-sun drying system.

# CHAPTER TWO

## LITERATURE REVIEW

### 2.1 Introduction

The use of sunlight directly as an energy source has proved in the past to be less economical than the use of other sources of concentrated sunshine (Arinze, 1973). The radiant energy of the sun is the only source of energy that influences directly or indirectly processes in the atmosphere and surface layer of the earth's crust since the sun itself is a gaseous sphere, the temperature of which varies from about 6000 $^0$K at the radiating surface to over 1 x $10^{6\ 0}$K at the tenuous outer atmosphere of the sun, and over 1 x $10^{7\ 0}$K in the deep interior (Bashiru et al., 1999).

The direct use of solar energy means using light, which is a form of electromagnetic radiation. About 9% of this lies in the extremely short and invisible ultraviolet region; about 40% is the visible light and the remaining 51% constitute the long waves (infra-red) (Bashiru et al., 1999).

The history of solar energy stretches back into the dim recesses of pre-history. The first person to use sun's energy on a large scale was Archimedes, who reputedly set fire on an attacking Roman fleet at Syracuse in 212BC (Garba et al., 1999).

Serious studies of the sun and its potentials began in the 17th century when Galileo and Lavosier utilized the sun in their researches. By 1700, diamond had been melted and by the early 1800's, heat engines were operating on energy supplied by the sun (Garba et al., 1999).

## 2.2 Previous Experimental Works on Solar Drying

Research work on solar drying for agricultural purposes has been going on for many years resulting in several dryer designs. H.B. Sanssuse invented the flat plate solar water heater during the second half of the 17th century. In the late 1950's a solar house was built at Denver, Colorado, where the over lapped glass plate solar air heater was tested (Lof, 1950).

Arinze (1973), in Nigeria, designed, constructed and tested solar energy model dryers, which utilized wind cups and chimney effect to obtain airflow through the dryer. The test revealed that for a 30mm to 59mm thick layer of corn receiving solar radiation directly through a transparent, plastic film was comparable to the figure obtained for a conventional high temperature heated air deep bed dryer. Obi (1984) reported that fibre glass as a cover material has the highest collector useful energy gain, and that the higher useful energy gain for the single fibre glass cover is mainly due to the higher heat removal factor or collector efficiency factor obtained by using this cover material.

The simplest type of solar dryer introduced for drying grains and fruits is the one in which the heating of the inlet ambient air and removal of moisture from the product take place in the same unit (Bassey, 1989).

El-Okene (2002) classified solar dryers into: direct dryers, indirect dryers, mixed mode dryers and hybrid dryers. He further explained that the direct solar dryer can be made from materials such as wood or metal sheet with saw dust, wood shavings or straw being used as the insulating material. The transparent material can be glass or

plastic film. It is noted that for these dryers, which operate at up to about $30^0$C above ambient temperature, drying rates are faster compared to open air drying.

In the indirect dryer, he noted that the main constraints on the use of these drying methods are inadequate airflow in the free convective mode and high cost. When a fan is used for air circulation, the design of the dryer is relatively straightforward. Bassey (1989) recommended that for an improved natural convection indirect solar dryer:

i. The collection area should be at least equal to the cross-sectional area of the dryer cabinet

ii. A chimney should not be used since the temperature in the chimney is close to ambient, giving rise to negligible buoyancy forces.

Awachie (1989) carried out a research on characteristics of improved solar dryer and reported that, the drier has a high energy gain of about 79.7JS $^{-1}$ m $^{-2}$ for a typical November day, and an overall efficiency of about 29%. Its moisture removal capacity is high and in addition, it has a drying advantage of about 2 times, when compares to the open air-drying method.

Kranzle and Bern (1980) showed that low-temperature drying appears well suited to solar thermal supplementation for drying most agricultural crops which do not need high temperature in order to retain their viability after drying. They recommended that if polythene cover is used on the heat collector, it should be replaced after each drying season, due to ultra violet radiation deterioration.

Mahendra et al. (1987) stated that in general, a cabinet type of dryer reduces the drying period by one half in comparison to open sun drying and that the shorter drying period improves the quality of agricultural products. Duffie and Beckman (1974) stated

that development of efficient solar drying processes would permit increased production of dried food while reducing industrial dependence on fossil fuels. They explained that technology was available for designing flat-plate solar collectors and thermal storage systems that could be used to heat air for conventional continuous food drying process.

Williams (1978) reported that a continuous drying process might require storage of up to 75 percent of the daily solar energy as thermal energy to provide continuous supply of air at $50^0$C to $70^0$C for over night use. In Nigeria, Adeniyi (1976) as reported by Eke (1991) investigated the principles of indirect solar heating. In his work, fresh pepper was successfully dried to 7 percent moisture content, wet basis and Okro to 8 percent moisture content.

Mulbaver et al. (1993) stated that in developing countries the uses of solar energy technologies in agriculture are most economically viable compared to industrialized countries. The introduction of solar drying system seems to be the most promising alternative in reducing post-harvest losses and could have significant contribution to steady food supply throughout the year.

A study carried out by Ahmad et al., (1997) using a flat-plate solar grain and fruit drying system showed that the cost of drying fruit and vegetable using the dryer is three times less than the cost of drying with conventional green-house type solar dryer and its dried fruit/vegetable output capacity is much higher (7 times) than the conventional system. Akani (1990) designed and constructed direct and indirect mode type free convection solar crop dryers using mud as a construction material. He found that wooden and soil black surfaces were as good as metal in terms of heat absorption.

Bassey (1989) pointed out that in Africa, very little success has been achieved in using solar energy because of inadequate knowledge of the drying problem, poor technical designs, high cost of improved drying technology, low level of production, inadequate storage facilities on farms, poor transportation facilities, underdeveloped distribution system, non-existent government policies to improve product quality, lack of locally produced materials, inadequate technical expertise, lack of interdisciplinary approach, lack of stable electricity supply and inadequate financial resources and planning.

He also pointed out that activities that can contribute to the future adoption of drying systems are:

i. Research on traditional open air drying

ii. Understanding the mechanisms involved in the operation of various types of dryers

iii. Reducing the cost of construction materials

iv. Improving the efficiency of dryers

v. Development of reliable testing procedures

vi. Studying and modeling the mechanism of moisture loss from various crops

vii. Developing better design procedures.

## 2.3 Configuration of Solar Dryers

A close investigation on different models of solar crop dryers has revealed that there are two major sections of the dryers, namely solar collector and drying sections.

A solar collector is normally made of a rectangular box with wooden, metal or mud framework, a transparent glass or plastic cover fixed in such a way that air plenum is created between the transparent cover and the absorber. Solar radiation at the earth surface has lengths from 0.3 to 3.0 micrometer (Ihekoronye and Ngoddy,1985). The solar radiation wavelengths are short waves. Short-waves radiation is able to pass through clear transparent substances, but black objects absorb it. After the short wavelength has been absorbed, the black materials emit radiation with wavelengths of more than 3.0 micrometer that is long-wave. Long-wave radiation cannot readily pass through some clear materials such as glass. In free convection solar dryer, airflow in the collector is as a result of air density variation, caused by the temperature difference. Thus, the hotter air rises thereby creating natural convection and the insulation minimizes heat losses to the surroundings.

A significant advantage of the use of a flat plate collector to produce energy is that it is responsive to both direct and diffuse solar energy components, thus it will provide useful heat energy even under cloudy sky conditions (Ihekoronye and Ngoddy, 1985). Duffie and Beckman (1974) reported that glass, as a transparent cover on the collector is the best material, as compared to plastic materials.

Dixon and Leslie (1978) stated that plastic materials such as polyethylene and fibreglass sheets, have been used in solar heaters, but they deteriorate with time and at high temperatures. Moreover, ultraviolet radiation discolours them, although they are easier to handle and cheaper than glass cover.

## 2.4 Theoretical Analysis of a Flat-plate Solar Collector

A typical flat-plate collector comprises an energy absorbing surface, a transparent cover to reduce convection and radiation losses to the surroundings, an air space for flow of the air in contact with the heat absorbing surface, side and bottom plate insulations to reduce conduction loss to the surroundings. The performance of a solar collector is shown by an energy balance equation that indicates the distribution of incident solar energy into useful energy and various losses.

### 2.4.1 Basic Flat-plate Energy Balance Equation and Collector Efficiency

Duffie and Beckman (1974) gave the basic flat-plate balance energy equation as:

$A_c I_t (\tau\alpha_e) = Q_u + Q_L + Q_s$ ..... (2.1)

Where:

$A_c$ = Collector area, $m^2$

$I_t$ = Total solar irradiation incident on the collector cover plate with transmittance equal to $\tau\alpha_e$, $W/m^2$

$\tau\alpha_e$ = transmittance – absorptance product of the collector, dimensionless factor

$Q_u$ = rate of useful heat transfer to a working fluid in the solar heat exchanger, W

$Q_L$ = rate of energy losses from the collector to the surroundings by radiation, convection, and by conduction through side and bottom plate insolation, W

$Q_s$ = rate of energy storage in the collector, W

The useful energy under steady state conditions is obtained from the three energy balance equation given by Duffie and Beckman (1974):

$q_u = F (\tau\alpha_e I - U_L (T_f - T_a))$ .....(2.2)

Where:

$q_u$ = Useful heat flow per unit area, $Wm^{-2}$

I = Solar irradiation $Wm^{-2}$

F = Collector efficiency factor

$T_F$ = Mean temperature of air in the collector, $^OC$

$T_a$ = Ambient temperature, $^oC$

$U_L$ = Total heat loss coefficient of collector, $W/m^2\ ^0C$

Considering the fact that there may be some heat loss from the collector, equation 2.2 becomes.

$$q_u = F_R (\tau\alpha_e I - U_L (T_{Fi} - T_a) \quad \text{.....(2.3)}$$

Where:

$F_R$ = Collector heat removal factor, $W/m^2\ ^0K$

By definition, instantaneous solar collector efficiency is

$$\eta = q_u / I \quad \text{.....(2.4)}$$

Where:

$\eta$ = instantaneous solar collector efficiency, %

Hill and Streed (1976) gave an expression for the instantaneous efficiency in term of both the useful energy and the airflow rate:

$$\eta = q_u / I = \frac{M C_P (T_{fo} - T_{fi})}{I} \quad \text{..... (2.5)}$$

Where:

qu = Useful heat flow per unit area, $Wm^{-2}$

I = Solar irradiation $Wm^{-2}$

$T_{fi}$ = collector air inlet temperature, $^0C$

$T_{fo}$ = Collector air outlet temperature, $^0C$

M = Mass flow rate of air per unit collector area, kg/s

$C_p$ = Specific heat of air at constant pressure, J/Kg $^0C$

Ta = ambient temperature, $^0C$

### 2.4.2 Collector Efficiency

Collector efficiency is given by Mahendra et al. (1987) as:

$$\eta = F^1\tau\alpha_e - U_L \frac{(T_f - T_a)}{I} \quad \text{.....(2.6)}$$

Where:

$\eta$= Instantaneous solar collector efficiency %

$F^1$ = Collector efficiency factor

$\tau\alpha_e$= Effective transmittance-absorptance product for the solar collector

$U_L$ = total heat loss coefficient of the solar collector, $W/m^2\ ^0K$.

$T_f$ = temperature of air leaving the collector, $^0C$

$T_a$ = ambient temperature, $^0C$

I = intensity of solar radiation per unit area of the absorbing surface, $W/m^2$

The above equation (2.6) is based on the performance of flat-plate collector operating under steady-state conditions and under the following assumptions:

i. The ends of the collector cover represent a small area that can be neglected.

ii. End passages provide uniform flow of fluid over the collector plate surface.

iii. There is one dimensional heat flow through the cover.

iv. There is a negligible temperature drop through the cover.

v. There is one dimensional heat flow through sides and bottom plate.

vi. Glass cover material is thin with the thickness ranging from 3mm to 5mm.

vii. The sky can be considered as a black body for long-wave length radiation at an equivalent sky temperature.

viii. Properties of the fluid and absorbing surface are independent of temperature.

ix. The effects of dust and dirt on the collector are negligible.

x. Shading of the collector absorbing plate is negligible.

### 2.4.3 Free Convection Heat Transfer in Solar Collectors

Free convection in a solar collector is a limiting factor to the collector efficiency. The mechanism of free (natural) convection is well spelt out by Holland (1978) as follows: Heat transfer in a stationary fluid is by conduction, just as in solid, and under steady conditions. In this case, the temperature field satisfies Laplace's equation. For a parallel layer of stationary fluid of thickness t and having temperature $T_h$ on one face and $T_c<T_h$ on the other, the heat flux, $q_s$ across the layer is given by

$$q_s = \frac{k\,(T_h - T_c)}{t} \quad \text{.....(2.7)}$$

Where:

$q_s$ = heat flux, $Wm^{-2}$

k = the thermal conductivity of the fluid, $Wm^{-1}\,K^{-1}$

$(T_h - T_c)$ = temperature drop across the two point, K

t = thickness of the parallel layer, m

The heat transfer coefficient, $h_S$ across the layer is defined as the heat flux per unit temperature difference:

$$h_s = \frac{q_s}{T_h - T_c} = \frac{K}{t} \quad \text{.....(2.8)}$$

The subscript, s, is used to denote the stationary condition.

A temperature variation is initially established by conduction, when a temperature difference is applied across a fluid. Since the density of most fluid depends on temperature, consequently, a density variation of the fluid is established by temperature difference across the layer. This non-uniform density in turn causes a local imbalance (called the buoyancy force) between the gravity force and the hydrostatic pressure force on a fluid element. The buoyancy force can drive a flow in the fluid and this flow is called free (or natural) convection.

Hence free convection is established principally by an existing external temperature gradient. After the flow of fluid has been initiated by temperature difference, the natural convection is then accelerated by free convective thermal energy mechanism through bulk movement of fluid. In which case the motion of the fluid flow initiated as a result of density variation is resisted by the viscosity (internal friction) of the fluid. The heat transfer by natural convection is influenced by:

i. Gravitational force due to thermal expansion ($\beta$)
ii. Viscous drag ($v$)
iii. Thermal diffusion ($\propto$)

The natural collection heat transfer, thus, depends on the gravitational acceleration, g, the coefficient of thermal expansion, $\beta$, the kinematic viscosity, $v = \mu/\rho$ and the thermal diffusivity, $\propto = k/\rho C_P$. The variables can be expressed in terms of dimensionless number called Nusselt number given by ASHRAE Handbook (1977) for horizontal or vertical planes, pipes, rectangular blocks, and spheres as:

$$Nu = \frac{hL}{k} = 0.56\ (Gr.\ Pr)\ 0.25 \quad \text{.........................................................(2.9)}$$

Where:

Nu = Nusselt number

h = Convective heat transfer, coefficient, $Wm^{-2} K^{-1}$

L = t = Characteristic dimension of the geometry of flow (thickness of air layer) m

k = thermal conductivity of fluid, W/mK

Gr = Grashof number

Pr = Prandtl number

The Grashof number is given as shown below by Holman (1981) as:

$$Gr = \frac{g\beta \Delta T L^3}{\mu^2} \quad \text{.......................................................................(2.10)}$$

Where:

Gr = Grashof number

g = Acceleration due to gravity, $ms^{-2}$

β = Volumetric coefficient of expansion of air, 1/K

ΔT = Temperature difference between the hot and cold surface, K

L = Plate spacing, m

μ = kinematic viscosity, Pa.s

Holman (1981) as also gives the Prandtl number as:

$$Pr = \frac{Cp}{k} \quad \text{.......................................................................................(2.11)}$$

Where:

Cp = specific heat of the fluid (J/kgK)

Pr = Prandtl number

K = Thermal conductivity of fluid, W/m K

The fluid properties, β, k, Cp, $\mu$ and density of the fluid, $\rho$ (kg/m$^3$) are all subject to variations with temperature and hence are not constant across the fluid in an enclosure.

It has been found that if Nu = hL/K= 1 and Rayleigh number (Ra) slightly greater than 1708, the air will be in motion by natural convection (Dixon and Leslie, 1978). The expressed Rayleigh and Nusselt numbers are as follows:

$$Nu = 1 + 1.44\left(\frac{1 - 1708}{Ra}\right) + \left\{\frac{(Ra)^{1/3}}{5830} - 1\right\} \quad \text{.....(2.12)}$$

and

$$Ra = 2737\,(1+2\alpha)^2\,\alpha^4\,\Delta T\,(100L)^3\,P^2 \quad \text{.....(2.13)}$$

Where:

Nu = Nusselt number

Ra = Rayleigh number

$= \frac{100}{T_m}$

$T_m$ = Mean temperature of fluid in collector, $^0$K

$T_m = \frac{Tp + Ta}{2}$

Tp = temperature of hot surface (absorber plate), $^0$K

Ta = temperature of ambient air, $^0$K

$\Delta T$ = Indoor-outdoor temperature difference, $^0$K

P = pressure in atmosphere, Kpa

L = width of solar collector, m

The airflow rate required to dry some quantity of crops when the optimum temperature difference and the amount of heat to be removed are known is given by ASHRAE Handbook (1977):

$$V = \frac{Q}{\rho Cp\ \Delta T} \quad \text{.....(2.14)}$$

Where:

V = air flow rate, $m^3$/min

Q = heat removal rate, J/min

Cp = specific heat of air at constant pressure, J/kg K.

$\rho$ = density of standard air, $kg/m^3$

$\Delta T$=indoor–outdoor temperature difference, K

### 2.4.4 Flow Due to Wind

In considering the contribution of natural wind forces in producing ventilation, account must be taken of average wind velocity, prevalent wind direction, seasonal and daily variation in velocity and direction, and local wind interference by nearby buildings, hills, trees and other obstructions.

ASHRAE Handbook (1977) gives an expression for evaluating the quantity of air passing through ventilation openings due to the wind as:

$$V_W = EAV \quad \text{.....(2.15)}$$

Where:

$V_W$ = volume of air flow rate, $m^3/s$

A = free area of inlet opening, $m^2$

V = wind velocity, m/s

E = effectiveness of openings (0.50 to 0.60 for perpendicular winds and 0.25 to 0.35 for diagonal wind).

## 2.5 Crop Drying Theory

Drying is a process of simultaneous heat and mass transfer. The heat is required to evaporate the moisture, which is removed from the drying product surface by the external drying medium, usually air. One of the basic considerations in drying agricultural crops is the role of moisture in the crop (Heldman and Singh, 1980). The chemical, physical and thermodynamic properties of bound water indicate that three types of bound water may exist in crops, namely:

i. Water molecules which are bound to ionic groups such as carboxyl and amino groups
ii. Water molecules which are hydrogen bonded to hydroxyl and amide groups
iii. Unbound free water found in interstitial pores in which capillary forces and soluble constituents cause lowering of vapour pressure

The moisture is removed with a certain degree of difficulty during the drying process, depending on the classification within which it falls. The above types of bound moisture are listed in order of decreasing difficulty of moisture removal. In addition, they are listed in reverse order which moisture would be removed, as the moisture content of the crop is decreased. This means that the free water would be evaporated and removed first, followed by the water molecules that are hydrogen bounded and finally, the moisture which is bounded to ionic groups. Each of the three groups of water in crops require different amount of energy for removal. The nature of moisture content of crops is the major focus in design and operation of crop dryers.

Crop drying is a function of two basic features, namely:

(a) the properties of the drying air, often known as external characteristics

### i. Relative Humidity

$$RH = \frac{Pv}{Pvs} \quad \text{.....(2.16)}$$

Where:

RH = Relative humidity, %

Pv = water vapour pressure in moist air, $N/m^2$

Pvs = partial pressure of water vapour at saturation, $N/m^2$

The partial pressure of water vapour at saturation is calculated from the following equation according to Brooker et al. (1974) as:

$$\frac{dPv}{d\,T_{abs}} = \frac{hfg}{T_{abs}} \quad \text{.....(2.17)}$$

Where:

hfg = latent heat of vaporization KJ

$T_{abs}$ = absolute dry-bulb temperature, K

The latent heat of vaporization (hfg) has to be calculated at the saturation condition and is given by Brooke et al. (1974) as:

$$hfg = 1075.90 - 0.57\,(T_{abs} - 459.69) \quad \text{.....(2.18)}$$

### ii. Saturation Pressure

The saturation pressure of water vapour in a moist air is given by Brooker et al. (1974) as:

$$Pvs = \exp\left(54.63 - \frac{12301.69}{T_{abs}} - 5.17\ \text{In}\ T_{abs}\right) \quad \text{.....(2.19)}$$

For $200^0\ F > T \geq 32^0 F$

And

$$Pvs = \exp\left(23.39 - \frac{11286.65}{T_{abs}} - 0.46 \ln T_{abs}\right) \quad \text{.....(2.20)}$$

For $0^0F < T > 32^0$ F

The pressure of vapour in equilibrium with a pure liquid at a given temperature is referred to as the vapour pressure of the liquid. Brooker et al. (1974) gives the mathematical relationship as:

$$Pv = \frac{Wv\ Rv\ T_{abs}}{Vv} \quad \text{.....(2.21)}$$

Where:

Pv = water vapour pressure, $N/m^2$ (Pa)

Wv = weight of water vapour, N

Rv = gas constant for water vapour

$T_{abs}$ = absolute dry-bulb temperature, K

Vv = Volume occupied by water pressure, $m^3$

### iii. Humidity Ratio

From ASHRAE Handbook (1977) the humidity ratio is given by

$$HR = 0.622 \frac{RH\ Pvs}{(P-(RH\ Pvs))} \quad \text{.....(2.22)}$$

Where:

HR = humidity ratio, (kg water/kg of dry air)

RH = relative humidity, %

Pvs = Pressure of water vapour at saturation, $N/m^2$

P = Barometric pressure = total pressure of moist air, $N/m^2$

The total energy content of a moist air sample per unit mass of dry air is known as the specific enthalpy.

iv. Dry-bulb and wet-bulb temperatures

v. Dew-point temperature

vi. Enthalpy

(b) The properties of the product known as the internal characteristics.

**i. Equilibrium Moisture Content**

Henderson and Perry (1976) expressed the equilibrium moisture content relationship mathematically as:

$$RH = e^{-CTM_E^n} \quad \text{.....(2.23)}$$

Where:

RH = equilibrium relative humidity, decimal

$M_E$ = equilibrium moisture content, dry basis, %

T = temperature, K

C,n, = constants depending on the product

Equilibrium moisture data can therefore be reported in terms of the constants C and n.

The equilibrium moisture properties of materials are important in storage and drying. If the relative humidity of the air in contact with a material is higher than the equilibrium relative humidity, there will be no drying. When the relative humidity is lower than the equilibrium, this will cause the moisture content to decrease (drying the product).

**ii. Latent Heat of Vaporization**

Latent heat of water is needed to evaluate the energy that will be supplied for evaporation of the amount of water from the wet crop to desired moisture content. It is given as :

$$hfg = \frac{M_a\, Cp\Delta T}{Mw} \quad \text{.....(2.24)}$$

Where:

hfg = Latent heat of vaporization of water, J/Kg

Ma = Mass of dry air flow rate through the crop, Kg/hr

Cp = Specific heat of air at constant pressure, J/Kg K

$\Delta T$ = temperature difference between drying air in plenum above and below the crop, $^0C$

Mw = Mass of the water evaporated, Kg

### iii. Internal Moisture Migration

Internal moisture migration is controlled by diffusion, capillarity and pressure gradient due to shrinkage. The general equation for diffusion of liquid through a porous solid (Brenndorfer et al., 1987):

$$\frac{dM}{dt} = D\frac{d^2 M}{dx^2} \quad \text{.....(2.25)}$$

Where:

M = Moisture content, dry basis,%

t = time, min

D = diffusion coefficient

X = distance from the particle surface, m

### iv. Drying Rate

Brenndorfer et al. (1987) recommend that the most informative means of presenting data on drying mechanism is by drying rate curves, rather than by drying curves.

A drying curve is a plot of moisture content versus time, whereas a drying rate curve is a plot of change in moisture content with time against the moisture content or against time.

The capacity of a thermal dryer depends on the rate of heat transfer and moisture (mass) transfer since water vapour must be removed during a drying process, heat of vaporization is supplied to achieve this. The material to be dried determines the quantity of heat to be supplied.

For biological materials, at the initial stage of drying, the rate of moisture migration to the surface of the drying product is high enough to keep the surface completely wetted. In this condition, the rate of drying is controlled by the rate of evaporation from the surface. This is known as constant rate drying period.

The constant drying rate is arrived at by the following equation (Henderson and Perry 1976):

$$\frac{dM}{dt} = hp\,A\,(P_w - P_a) \quad \text{.......}(2.26)$$

$$\frac{dM}{dt} = \frac{hcA}{L}\,(T_a - T_w) \quad \text{.......}(2.27)$$

Where:

$\frac{dM}{dt}$ = drying rate Kg of water/sec

hp = water vapour transfer coefficient $kg/m^2\,s$

A = water surface area $m^2$

$P_w$ = water vapour pressure at Tw; $kg/m^2$

$P_a$ = water vapour pressure at Ta; $Kg/m^2$

hc = thermal conductance of air film $W/m^2$ K

L = latent heat of vaporization J/Kg

$T_a$ = temperature of hot air $^0C$

$T_w$ = temperature of wet surface $^0c$

M = mass of water, kg

t = time, sec

As the constant rate drying period progresses, an intermediate period could be attained. This is the period at which part of the surface is dried while part is still wet. The dry part continues to increase, while the wet part decreases. At this stage the rate of drying is governed partly by the rate of moisture evaporation from the wet parts and partly by the rate of internal moisture migration within the particle. The proportion of the dry surface increases until the surface becomes completely dry and internal moisture migration becomes the rate-controlling factor. This brings in the second stage of the drying rate called falling-rate drying period.

**v. Falling-Rate Drying Period**

As drying proceeds, a point is reached at which the rate of transfer of moisture within the material to the surface is less than the rate of evaporation from the surface and the surface begins to dry out. At this point the falling rate-drying period starts, and the moisture content of the crop is known as the critical moisture content.

A number of methods have been used to characterize drying at the falling rate. This includes the empirical methods. Falling rate drying period of corn is given by Henderson and Perry (1976) as:

$$t = A \ln MR + B \ln (MR)^2 \quad \text{.....(2.28)}$$

But MR = $\frac{M - M_e}{M_o - M_e}$ .....(2.29)

Also A = 1.862 + 0.00488T

B = 427.364 Exp (-0.03301T)

Where:

t = time to dry to critical moisture content, hr

$M_R$ = Moisture ratio

M = Moisture content, %

$M_o$ = initial moisture content, %

$M_e$ = equilibrium moisture content at relative humidity of the drying air, %

T = Drying air temperature, $^0F$

A and B = constants

**vi. Rate of Water Removal from the Drying Crop and Energy Supply to Heat the Air**

Drying with heated air is an adiabatic process, the energy for moisture evaporation being supplied by a reduction in temperature of the air. The wet-bulb (adiabatic humidification) lines of the psychrometric chart can be used to calculate the water removal rate and the energy that must be supplied to heat the air (Henderson and Perry, 1976).

**vii. Rate of Water Removal**

Air initially at dry-bulb temperature $t_1$ and humidity ratio $W_1$ is heated to a dry-bulb temperature $t_2$ and humidity ratio $W_2 = W_1$, the heated air is then passed through a material to be dried. The state point moves up the wet-bulb line and the air exhausts at dry-bulb temperature $t_3$ and humidity ratio $W_3$. The water removal rate $W_m$ is:

$$W_m = \frac{V_a}{V_b}(W_3 - W_2) \quad \text{.....(2.30)}$$

Where:

$W_m$ = water removal rate, Kg/sec. $m^2$ sectional area of air flow

$V_a$ = air flow rate, $m^3$/sec $m^2$

$V_b$ = humid volume of air at point of rate measurement, $m^3$/kg-dry air

Total water removed from a product is given by

$$W_t = \frac{(M_{id} - M_{fd})}{100} DM \quad \text{.....(2.31)}$$

Where:

$W_t$ = total water removed, kg

$M_{id}$ = initial moisture content (before drying) dry basis, %

$M_{fd}$ = final moisture content (after drying) dry basis, %

Dm = dry matter (bone dry), kg

**viii. Thin Layer Dryer**

In thin layer drying, the drying product is said to be drying uniformly at given boundary conditions. There is no gradient assumed during the dry rate. Vegetables and fruits, which have high moisture content, are normally dried in thin layers. Henderson and Perry (1976) expressed thin layer drying by the equation:

$$\frac{M - M_E}{M_o - M_E} = Ae^{-kt} \quad \text{.....(2.32)}$$

Where:

M = Moisture content, dry basis, % after a period of time t

$M_E$ = equilibrium moisture content, %

$M_O$ = moisture content, dry basis, % at the beginning of the drying period, at time zero

K = Drying constants

t = time, hr

A = materials (particles) shape constant

## 2.6 Fan Performance

In forced convection dryers, the fan is the primary mover of air. It then becomes necessary to consider fan performance in relation to the dryer performance. According to Henderson and Perry (1976), the power output of a fan is expressed in terms of air power, which represents work done by the fan and it is given as:

$h_{PA} = Q\gamma H$ .....(2.33)

Where:

$h_{PA}$ = air power, W

Q = Volume of air delivered per unit time, $m^3/s$

$\gamma$ = specific weight of fluid (air), $kg/m^3$

H = total head, m

The total head against which the fan works is given by church (1972) as:

$$H = \frac{K^1 \phi V^2}{g} \quad \text{.....(2.34)}$$

Where:

$K^1$ = overall pressure coefficient

$V^2$ = velocity of the air, m/s

g = acceleration due to gravity, $m/s^2$

$\phi$ = overall head coefficient at the point of maximum efficiency, which takes the value from 0.9 to 1.20

Church (1972) gave the value of $K^1$ as:

$$K^1 = \frac{1}{2\phi^2} \quad \text{.....(2.35)}$$

Wallis (1961) expressed the shaft power as follows:

$hps = 2\pi T n$ .....(2.36)

Where:

hps = fan shaft power, W

T = torque, N-m

n = speed, rps

Henderson and Perry (1976) state that the total mechanical fan efficiency is based upon static power which is always less than total power, the static efficiency is not a true index of maximum performance, therefore its use is not recommended.

The mechanical fan efficiency is given by:

$\eta_t = hp_A/hp_s$ .....(2.37)

Where:

$\eta_t$ = total mechanical efficiency of fan, %

$hp_A$ = air horse power, hp

$hp_s$ = fan shaft horse power, hp

The maximum recommended stress for most materials from which fan components are made is of the order 1/4 to 1/5 of the ultimate breaking stress, as stated by

Osborne (1966) and the maximum shear stress is taken as about 2/3 of the maximum permissible direct stress.

Bearing this in mind a simplified approach to the mechanical design of fan is out lined as follows:

**i. Blade**

The blades may be considered as beams with rigid support at back plate and shroud. The maximum bending moment is given by.

$$M_b = \frac{Wb}{12} \quad \text{.....(2.38)}$$

Where:

$M_b$ = Maximum bending moment, N-m

W = total distributed load on the blade, N

b = blade width, m

The total distributed load on the blade comprises the centrifugal forces and the pressure differences across the blade.

In most practical cases the force F is of greater significance.

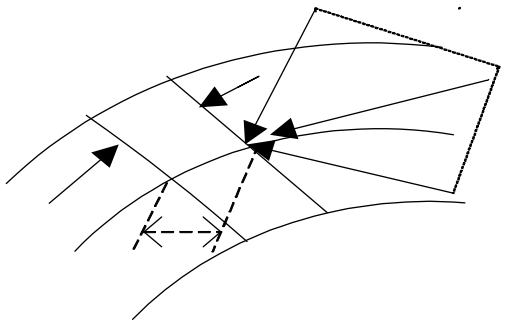


Figure 2.1 Force on fan blades

Considering an element of the blade of width b, thickness t, and length L, as shown in Figure 2.1, the force normal to the element is given by (Osborne ,1966):

$$dF^1 = dF \cos \beta = bt L \frac{\rho}{g} \omega^2 r \cos \beta \quad \text{.....(2.39)}$$

Where:

L = blade length, m

b = blade width, m

$\rho$ = density of blade material kg/m$^3$

$\omega$ = angular speed, rev/sec

$\gamma$ = blade rotation radius reference to fixed position, m

$\beta$ = blade angle (degrees)

t = thickness of blade, m

g = acceleration due to gravity, m/s$^2$

The maximum bending moment is given by

$$M_{max} = \frac{dF^1 b}{12} = \frac{b^2 t \rho}{12 g} \omega^2 \gamma L \cos \beta \quad \text{.....(2.40)}$$

All the symbols are as defined in equation 2.39.

The section modules Z is

$$Z = \frac{2t^3 L}{12 t} = \frac{t^2 L}{6} \quad \text{.....(2.41)}$$

Thus, the maximum bending stress is

$$M_{max} = \frac{b^2 \rho \gamma \omega^2 Z \cos \beta}{2 t g} \quad \text{.....(2.42)}$$

The symbols are similarly defined. If the blades are welded to the shroud and back, and the stress in the weld is

$$\tau = \frac{\rho \omega^2 \gamma}{g} 2L L_w \cos 45 \quad \text{.....(2.43)}$$

Where:

$\tau$ = Stress in the weld

$\rho$ = Density of blade material, $kg/m^3$

$\omega$ = Angular speed Rev/Sec.

$\gamma$ = Blade rotation radius reference to fix position, m

L = Blade length, m

$L_w$ = Weld length, m

g = Acceleration due to gravity, $mls^2$

**ii. Fan Shaft**

The fan shaft may be treated as a beam carrying the impeller as point loads if the shaft is long. The stress situation in the shaft must be considered in three different ways (Hall et al., 1980)

a. Maximum bending stress for solid shaft, $S_b$ (tension or compression)

$$S_b = \frac{M_b r}{I} = \frac{32 M_b}{\pi d^3} \quad \text{..... (2.44)}$$

b. $$S_S = \frac{16}{\pi d^3} \sqrt{(k_b M_b)^2 + (K_t M_t)^2} \quad \text{.....(2.45)}$$

Where:

$M_b$ = Bending moment, N m

d = solid shaft diameter, m

$k_b$ = Combined shock and fatigue factor applied to bending moment

$k_t$ = combined shock and fatigue factor applied to torsional moment

$M_t$ = Torsional shear stress, N m

r = radius of the shaft, m

I = rectangular moment of inertia, $m^4$

$S_S$ = allowable shear stress, $N/m^2$ (55 $MN/m^2$ for solid shaft without keyway and 40 $MN/m^2$ for shaft with keyway).

**iii. Pressure Head**

Kazantsev (1977) gave a relationship by which total pressure head developed by a centrifugal fan, at standard atmospheric pressure of 760mm Hg, 50% relative humidity and temperature of $20^0$c, can be calculated.

$$H^{3/4} = \frac{nv^{1/2}}{n_{sp}} \quad \text{.....(2.46)}$$

Where:

H = Total pressure head, mm $H_2O$

n = Radial speed (number of revolution per minute) rpm

$n_{sp}$ = Specific speed or specific number of revolution, rpm

v = Volume of air flow rate $m^3/h$

## 2.7 Drying Efficiencies

It is useful to establish and standardize a means of evaluating the thermodynamic performance of a drying operation or system. This would enable comparison between two or more dryers.

For solar dryers, Brenndorfer et al., (1987) recommended three criteria for performance evaluation. These criteria have the advantage of enabling the evaluation of the separate components. They are:

i. system drying efficiency

ii. collection efficiency

iii. moisture pick-up efficiency

### 2.7.1 System Drying Efficiency ($\eta_d$)

This is the ratio of the energy required to evaporate the moisture to the energy supplied to the dryer.

This is expressed by the formula (Brenndorfer et al., (1987) :

$$\eta_d = \frac{M_w L_v}{I_c A_c t} \quad \text{..... (2.47)}$$

Where:

$\eta_d$ = System drying efficiency, %

$M_w$ = Weight of water evaporated, kg

$L_v$ = Latent heat of vaporization, J/kg

$I_c$ = Average daily insolation incident on collector, $Wm^{-2}$

$A_c$ = Collector area, $m^2$

t = Drying time, s

The system drying efficiency is a measure of the overall effectiveness of a drying system and so it often quoted.

Brenndorfer et al. (1987) gave the value of the system drying efficiency of natural convection dyers as 10-15%, and 20-30% for force convection dryers.

### 2.7.2 Collector Efficiencies ($\eta_c$).

Collector efficiency is a measure of how effectively the energy available in the insolation incident upon a collector is transferred to the air flowing through the collector.

This is expressed by the formula (Brenndorfer et al., (1987) :

$$\eta_c = \frac{V.\ \rho.\ \Delta T.\ C_p}{A_C\ I_C} \quad \text{.....} \quad (2.48)$$

Where:

$\eta_c$ = Collector efficiency, %

V = Volumetric flow rate of air, $m^3\ s^{-1}$

$\rho$ = Air density, kg $m^{-3}$

$\Delta T$ = Air temperature elevation, $^0C$

$C_p$ = Air specific heat, J $kg^{-1}\ ^0C^{-1}$

$A_c$ = Collector area, $m^2$

$I_c$ = Insolation on collector surface, $Wm^{-2}$

### 2.7.3 Pick-up Efficiencies ($\eta_p$)

The pick-up efficiency is the ratio of the moisture 'pick-up' by the air in the drying chamber to the theoretical capacity of the air to absorb moisture. This parameter is useful for evaluating the actual evaporation of moisture from the commodity being

dried. It is a direct measure of how efficiently the capacity of heated air to absorb moisture is utilized.

This is expressed by the formula (Brenndorfer et al., (1987) :

$$\eta_p = \frac{M_o - M_t}{v \cdot \rho \cdot t \cdot (h_{as} - h_i)} \quad \text{.....(2.49)}$$

Where:

$\eta_p$ = Pick–up efficiency, %

$M_o$ = Mass of commodity at time t = 0, kg

$M_t$ = Mass of commodity at time t, kg

V = Air flow rate, $m^3 s^{-1}$

$\rho$ = Air density, kg $m^{-3}$

t = Drying time, sec

$h_{as}$ = Adiabatic saturation humidity of the air entering the dryer, kg $kg^{-1}$

$h_i$ = Absolute humidity of air entering the drying chamber, kg $kg^{-1}$

$M_O - M_t = M_w$ = mass of moisture evaporated in time t, kg

## 2.8 Tomato Production in Nigeria

### 2.8.1 Introduction

Tomato (*lycopersicon escalentum*) is a fleshy berry belonging to the family solenaceae. It's shaped like a globe, or depressed at both ends. When young it is hairy but becomes smooth and shiny when ripe. Originating in Central and South America, the tomato was not recognized as a useful vegetable until the 1800s, when grown as staked plants (ICS, 2004). Tomato is green when mature and turns red or yellow when ripe. The colours are due to pigments, lycopene and carotenoids. Lycopene is responsible for the red colour (Kordyles, 1990). Maud (1991) reported that tomatoes are about 2 to 10cm diameter, and contain numerous seeds which are hairy and light

brown. Ripe tomatoes contain about 94% water and are good source of Vitamins A and C (Kordylas, 1990) and low in calories (ICS, 2004).

Tomato is one of the fruit often in great demand, consumed wholly by every household, used as ingredient in soup and stew preparation and condiments in other food items.

### 2.8.2 Tomato Production System and Zones

Tomato is perhaps the most popular vegetable crop grown all over Nigeria. It dominates the largest area under production among vegetable crops (Ramalan et al. 1998). Both the wet and dry season cropping contribute immensely to the national requirement, but the bulk of the product is from the dry season cropping (Aman et al., 1986).

Rufa'i (1999) reported that tomato is currently the most important commercial vegetable grown in Nigeria. Large-scale tomato production in Nigeria is mainly under irrigation during the dry season (Sept – March) when temperatures are mild and humidity moderate. The rainfed crop (June – Sept) is also important due to continuous demand for fresh tomato.

The crop stays for up to 3 months in the field and yields between 20 – 50t/ha. The period between March-June is normally too hot for successful tomato production (Rufa'i, 1999).

The area of major production is the Northern part of Nigeria (between latitude $8^{o}$N to $13^{o}$N) in areas like Kaduna, Kano, Jigawa, Katsina, Sokoto, Plateau, Zamfara, Bauchi,

Borno and Gombe states. These areas are responsible for 55% of the total national production as shown in Table 2.1. The Natural features of the major producing region, especially the presence of flood-prone plains and river basins and above all the development of vast irrigation lands create conditions that greatly favour the development of this crop. Tomatoes are mostly marketed in the southern part of Nigeria and neighbouring countries (Aman et al. 1986).

**TABLE 2.1: PRODUCTION BY SMALLHOLDER FARMERS ('000 METRIC TONNES) FOR TOMATO**

| S/NO. | STATE/ADP | TOTAL | | | | |
|---|---|---|---|---|---|---|
| | | **1999*** | **2000*** | **2001*** | **2002*** | **2003**** |
| 1 | Benue | 44.48 | 42.42 | 46.99 | 40.87 | 48.41 |
| 2 | Nassarawa | 16.01 | 13.93 | 12.73 | 13.38 | 13.00 |
| 3 | Plateau | 108.26 | 120.56 | 114.3 | 119.00 | 119.00 |
| 4 | Bauchi | 51.13 | 54.46 | 54.52 | 68.71 | 73.42 |
| 5 | Kaduna | 97.48 | 98.84 | 68.58 | 70.00 | 68.00 |
| 6 | Zamfara | 112.11 | 112.005 | 112.59 | 112.59 | 118.00 |
| 7 | Sokoto | 31.21 | 34.0 | 34 | 34 | 34.00 |
| 8 | Kebbi | 32.00 | 38.41 | 40.40 | 42.40 | 48.00 |
| 9 | Kogi | 14.16 | 15.39 | 15.93 | 18.00 | 17.90 |
| 10 | Fct | 6.89 | 8.62 | 9.62 | 12.28 | 20.65 |
| 11 | Niger | 36.49 | 49.24 | 37.14 | 33.08 | 35.20 |
| 12 | Kwara | 0 | 2.51 | 2.8 | 2.70 | 2.70 |
| 13 | Katsina | 59.12 | 59.2 | 61 | 62.78 | 60.78 |
| 14 | Kano | 179.21 | 125.1 | 132.12 | 132.12 | 133.69 |
| 15 | Jigawa | 0 | 42 | 48.5 | 50.52 | 59.52 |
| 16 | Yobe | 0 | 0 | 0 | 0 | 9.18 |
| 17 | Gombe | 83.71 | 85.71 | 91.86 | 93.53 | 90.81 |
| 18 | Taraba | 21 | 32.37 | 35.55 | 35.55 | 35.89 |
| 19 | Adamawa | 5 | 6.97 | 7.52 | 7.52 | 7.52 |
| 20 | Borno | 52 | 60 | 64.20 | 64.20 | 64.00 |
| 21 | Lagos | 27.61 | 30.78 | 37.39 | 35.67 | 40.40 |
| 22 | Ogun | 38.34 | 47.89 | 42.78 | 43.89 | 43.22 |
| 23 | Oyo | 47.87 | 49.71 | 53.42 | 61.50 | 57.09 |
| 24 | Ondo | 4.56 | 4.92 | 5.52 | 5.89 | 6.26 |
| 25 | Ekiti | 4.99 | 5.38 | 5.56 | 4.67 | 4.43 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 26 | Osun | 7.90 | 8 | 9.00 | 9.00 | 9.00 |
| 27 | Edo | 16.81 | 17.2 | 16.10 | 16.10 | 16.10 |
| 28 | Delta | 4.01 | 6.44 | 6.72 | 6.87 | 6.87 |
| 29 | Rivers | 26.41 | 27.70 | 23.43 | 23.64 | 23.64 |
| 30 | Bayelsa | 0 | 0 | 0 | 0 | 0 |
| 31 | Imo | 0.4 | 0.49 | 0.52 | 0.52 | 0.54 |
| 32 | Abia | 0.13 | 0.14 | 0.14 | 0.16 | 0.18 |
| 33 | Akwa Ibom | 0.05 | 0.06 | 0.06 | 0.06 | 0.06 |
| 34 | Cross River | 10 | 11.18 | 9.19 | 9.19 | 9.19 |
| 35 | Anambra | 20.29 | 21.64 | 22.32 | 19.94 | 18.33 |
| 36 | Enugu | 18.42 | 19.87 | 19.61 | 17.86 | 18.22 |
| 37 | Ebonyi | 0.72 | 7.63 | 8.90 | 8.90 | 9.24 |
| 38 | National | 1,078.78 | 1,260.794 | 1,251.00 | 1,284.06 | 1,324.43 |

Sources: * Obtained from internet (www.pcuagric.org), June, 2004
** Obtained from PCU, Kaduna Zonal office, 2004.

### 2.8.3 Processing and Storage of Tomato

Tomatoes are highly perishable (Peterson, 1977). Usually they are processed immediately after harvest into puree or paste and canned or bottled (Desrosier, 1977).

In the developed countries, apart from canning industries that process and can tomato produced, home canning facilities are also available and affordable; as a result, most tomatoes harvested are processed and canned. The third world countries suffer losses of such perishable produce, because canning industries are either not available or their operational level is very low to utilize all the tomato fruits produced, and in some cases, other shortcomings such as access road, transport facilities long distance from farm to factory etc. constitute delay in delivery (Ladan et al., 1997). Peterson (1977) had estimated that about 60% of tomato produced in the third world countries rot away annually. These losses give rise to short supply and high price during the off-season.

### 2.8.4 Drying Areas of Tomato in Nigeria

The only available method of processing tomato in most of the third world countries is through drying under the sun. In Nigeria, drying tomato in commercial quantity is associated with the areas of production especially in areas where the commodity is marketed.

The major drying centres where tomatoes are dried in commercial quantities are: Kwanar Gafan and Danbatta (Tomas dam) in Kano state, Kwanar Kazaure in Jigawa State, Dutsen Wai and Auchan Kaduna state, Gusau and shinkafi in Zamfara state and Jire in Gombe state among others.

## 2.9 Quality of Food

The action of applying heat to a material in order to dry it does not merely remove the moisture but can also affect the quality of the dried product (Brenndorfer et al., 1987). These effects are many and varied; the discolouration of the material during drying, migration of soluble constituent from interior to the surface of the material, case hardening, loss of volatile constituents and dehydration**.**

Every food has a characteristic appearance, odour, taste and feel which we associate normality. Any deviation is suspect. Change in the colour of foods may be an indication of change in their nutritive value.

According to Moreau (1979), the organoleptic qualities of food is usually altered by the presence of micro-organism, of particular interest is the presence of micro-fungi (moulds) on the surface and within the product.

The factors which control the type and extent of microbial food spoilage are the moisture content, the temperature, the oxygen concentration, the nutrients available,

the degree of contamination with spoilage organism and the presence of growth inhibitors (Brenndorfer et al., 1987).

According to Onwuka et al. (2002), the common bacteria contaminating vegetable products irrespective of drying method were E. *coli* , S. *aureus* and L. *planetarium*, while the common fungi were A. *niger* , R. *nigricaus* and M. *spinosis*.

# CHAPTER THREE

# METHODOLOGY

## 3.1 Introduction

The methodology adopted in this study consists of the following:

- Preliminary survey
- Conceptualization of dryer configuration
- Design of the conceptualized dryer
- Construction of the designed dryer
- Evaluation of the dryer

## 3.2 Preliminary Survey

A survey of the study area was carried out with respect to tomato production, marketing, drying and storage.

### i. Site Selection

Based on the results of preliminary survey presented in section 4.2, Kwanar Gafan in Garin Malam local government area in Kano state was selected as the study area for the preliminary study on tomato production, processing and storage.

Kano state has the highest production figure of tomato in Nigeria and produces an average of 140,000 metric tonnes annually, accounting for 12% of national production as shown in Table 2.1. The state is also the largest market for both fresh and dried tomato in the Northern part of Nigeria (Ibrahim, 2004). Kano state is in the Sudan Savanna ecological zone of Nigeria. The zone stretches from the Sokoto plain through the northern section of the high plains of the Chad Basin. It consists mainly of mature woodland with a

fairly uniform structures of two distinct types associated with short grasses (KNARDA, 1994). Little traces of natural vegetation is said to remain, as large areas are continuously cultivated. However, the zone provides the most favourable condition for the production of crops and livestock.

Kano state lies between latitude $10^{o}35'N$ and $12^{o}40'N$ of equator and between longitude $7^{o}42'$ E and $9^{o}15'E$ of Greenwich Meridian, and occupies a land area of about 20,000 square kilometres. The state is bordered in East and Northeast by Jigawa state, in the South by Bauchi and Kaduna states and in the West by Kaduna and Katsina states.

The climate is characterized by two distinct seasons, the dry season that spans from October to May and the raining season is concentrated in the months of June to September. The mean daily maximum temperatures are $33.1^{o}C$ and $15.85^{o}C$ respectively for the two seasons.

Crops cultivated under rain-fed condition are Millet, Sorghum, Cowpea, Groundnut, Beans, Cassava, Cotton and Maize. In the dry season, crops cultivated especially in the Fadamas and some large-scale irrigation schemes in the state, are Onions, Tomatoes, Pepper, Lettuce, Cabbage and Sugar cane.

ii. **Production and Drying Practice of Tomato at Kwanar Gafan**

To have a good estimate of tomato production and method of drying practice at Kwanar Gafan and some other villages around it, questionnaires (appendix A1,A2) were developed and administered to collate needed information by asking questions and filling the questionnaire by the researcher on the existing farm practice and drying method from farmers and professional local tomato dryers. The questionnaire for the farmer was administered at three villages around the study area. The villages visited

were Dakasoyi, Dorawar sallau and Gafan where 30 farmers were interviewed. The questionnaire for the professional local tomato dryers was administered at the Kwanar Gafan market where the farmers were located.

### 3.3 Conceptualization of the Dryer configuration

Based on the quantity of tomatoes required to be dried per batch as reported in section 4.2 (i), and the shape and size of the blower to be used, the configurations of the dryer will include a rectangular drying chamber of dimensions 30m x 1.35m x 0.7m with an inlet hole and outlet hole on the ends so as to facilitate the entry of ambient drier air from one end, and the exit of warmer moist air on the other end, and the blower was attached to the inlet hole as shown in figure 3.1.

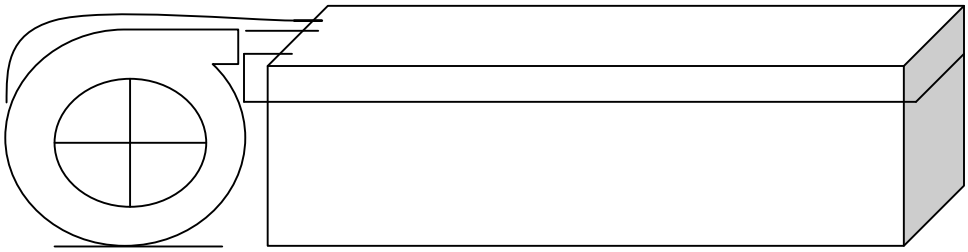


FIG. 3.1 Sketch of Forced Convection Solar Dryer

### 3.4 Design Consideration

The design of solar crop dryer requires extensive design experience and a good knowledge of environmental factors such as ambient temperature, insulation, wind speed and direction and humidity. Beside these ambient environmental parameters, the designer needs to know:

I, the quantity of product to be dried.
ii, the initial and the required final moisture content of the product.
iii, safe drying rate and temperature for the product.

iv, the total amount of energy required to dry the product within the drying requirement.

### 3.4.1 Determination of Dryer Capacity

Based on the results from the questionnaires (Appendix A-1,A-2) presented in section 4.2, which were administered to the farmers and the professional local tomato dryers. The capacity of the intervention dryer was chosen to be 400kg (10 baskets) of fresh tomatoes per batch**.**

### 3.4.2 Determination of Quantity of Water to be Removed.

Lutz & Hardenburg (1967), said that ripe tomatoes have a moisture content of about 94.1% wet basis, while the mature green tomatoes have the moisture content of about 93%, and that the average safe storage moisture content of dried tomatoes is about 7% wet basis. The initial moisture content of tomatoes for this research consideration is taken to be 93.5% wet basis.

Having established that the optimum dryer capacity is 400kg of fresh tomatoes at the estimated 93.5% moisture content, the water removed by drying from 93.5% moisture content to the safe storage 7% moisture content is calculated as follows:

$$D_M = W_M - \frac{W_M M_{CIW}}{100} \quad \text{----------(3.1)}$$

where :

$D_M$ = dry matter of the tomatoes, kg

$W_M$ = Weight of fresh tomatoes, kg

$M_{CIW}$ = initial moisture content of tomatoes wet basis%

The dry matter Dm of the 400kg of tomatoes is obtained as follows:

$$D_M = 400 - \frac{400 \times 93.5}{100}$$

$$= 400 - 374 = 26\text{kg}$$

The quantity of water removed is given as

$$W_t = \frac{Mcid - Mcfd}{100} D_M \quad - - - \text{----------(3.2)}$$

Where: $W_t$ = quantity of water removed, kg.

$D_M$ = dry matter weight, kg

Mcid = initial moisture content of product, dry basis %

Mcfd = final moisture content of product dry basis%

The initial moisture content dry basis is

$$Mcid = \frac{93.5}{100 - 93.5} = \frac{93.5}{6.5} = 14.38\ \%$$

The final moisture content dry basis is

$$Mcfd = \frac{7}{100 - 7} = \frac{7}{93} = 0.075\%$$

The quantity of water to be removed in drying from the initial to final moisture content is:

$$W_t = \left( \frac{14.38 - 7.5}{100} \right) \times 26 = 371.92\text{kg}$$

Therefore 371.92kg of water has to be removed in order to dry 400kg of tomatoes from 93.5% moisture content wet basis to 7% moisture content wet basis.

### 3.4.3 Determination of Collector Useful Energy Gain

Kordylas (1990) recommended that temperature range of between 35$^{o}$C and 63$^{o}$C are quite satisfactory for drying fruits and vegetables. It is important to know that most enzymes are destroyed at temperatures of above 60$^{o}$C. This project aims at constructing tomatoes dryer that will generate temperature above 35$^{0}$C and less than 60$^{O}$C of the drying air, however, the average highest maximum monthly temperature at Kadawa (area of study) is 42.3$^{o}$C in the months of March - April (IAR, 2000).

The heat energy required to evaporate the calculated 372.05kg of water is the collector useful energy gain. It can be calculated by applying the sensible heat added to the material and the heat of evaporation as shown in the following equation:

$$E = E_1 + E_2 = Wm\ C_{pm}\ (T_2 - T_1) + L_v W_t \quad \text{----------(3.3)}$$

i.e. $E_1 = Wm\ C_{pm}\ (T_2 - T_1)$

$E_2 = L_v W_t$.

Where :

- $E$ = Collector useful energy gain, KJ
- $E_1$ = Sensible heat added to the material, KJ
- $Wm$ = Weight of material (fresh tomatoes), Kg
- $C_{pm}$ = Specific heat of material, KJ/Kg$^oC$
- $T_2$ = Temperature of air inside dryer, $^oC$
- $T_1$ = Collector inlet temperature, $^oC$
- $E_2$ = Heat of evaporation, KJ
- $L_v$ = Heat of vaporization, (KJ/Kg) at the temperature $T_2$
- $W_t$ = Weight of water to be removed, kg.

Heat of vaporization at 45$^oC$ = 1029.3 Btu/lb (ASHRAE, 1977)

But, 1 Btu/lb = 2.326 KJ/kg

Therefore, 1029.3 Btu/lb x 2.326 KJ/kg = 2394.1518 KJ/kg.

also

$C_{pm}$ (tomato) = 0.945 Btu/lb $^oF$ (Lutz & Hardenburg ,1967)

1 btu/lb $^oF$ = 4.187 KJ/kg$^oC$.

Therefore, 0.945 Btu/lb$^oF$ x 4.187KJ/kg$^oC$ = 3.956 KJ/kg $^0C$

$$E_1 = W_M\ C_{pm}\ (T_2 - T_1) \quad \text{---------- (3.4)}$$

$= \quad 400 \times 3.956 (45 - 30) = 23740.29$

$E_2 = L_v W_t$ ---------- (3.5)

$= \quad 2394.15 \times 371.92 = 890439.566$

$E = E_1 + E_2$

$= \quad 23740.29 + 890719.566 = 914459.856$

$= \quad 914456.856$ KJ

Thus: 914456.86 KJ heat energy is required to dry 400kg of tomatoes from 93.5% moisture content wet basis to 7% moisture content wet basis.

### 3.4.4 Determination of Theoretical Drying Period

A basket of fresh tomato commonly used in the market (study area) weighs averagely 40kg, as reported in section 4.2, if this is sliced and spread on surface it will cover an average area of $3.0m^2$ to $5.0m^2$ for the local and Eke's type of slice respectively.

For this experiment where the two types of slice were to be subjected to same condition, an average area of $4.0m^2$ was chosen per basket. Therefore, a total of 40 $m^2$ was provided for 400kg (10 baskets) of tomatoes. Since tomato surface will serve as collector surface area, useful energy for drying the crop can be determined approximately for a horizontal collector as given by Duffie and Beckman (1974):

$Qu = Ac\ F_R\ \tau_{\alpha e}\ I_H$ ---------- (3.6)

Where: $Ac$ = Collector area ($m^2$)

$F_R$ = heat removal factor (approximately 0.7 for an air- collector)

$\tau_{\alpha e}$ = Effective transmittance – absorptance product (approximately 0.5 for transparent white polythene).

$I_H$ = total solar irradiation intensity per unit area.

The monthly average daily extraterrestrial solar radiation on horizontal surface between the months of February to June is approximately 500 $W/m^2$ for Kano location (Fagbenle, 1991).

Assuming that the ambient air and collector inlet temperatures are same therefore,

$$Q_U = 40m^2 \times 0.7 \times 0.5 \times 500W/m^2$$

$$= 7000W$$

$$= 7.0KJ/s$$

The energy required per hour becomes:

$$7.0 \times 3600 = 25200KJ/hr$$

The heat energy required per day assuming 10 hours of daily sun shine is

$$25200KJ/hr \times 10hr = 252000KJ/day.$$

Recall that E = 914456.856KJ (Section 3.4.3)

Therefore the period that will be required to dry the tomato is

$$\frac{914456.856KJ}{252000\ KJ/day} = 4\ days$$

### 3.4.5 Determination of Air Flow Rate

The fan, which is the air blower, is the primary mover of the air in a forced convection drying system. The blower flow rate is directly related to the dryer capacity.

In order to determine the required air flow rate, the amount of water to be removed from the product from 93.5% initial moisture content wet basis to 7% moisture content wet basis was calculated as in section 3.4.

$D_M$ =26kg and $W_t$ =372.05kg

While the total energy required to removed the water from the product, E is approximately 914459.83KJ, useful energy $Q_u$ = 7.9379KJ/S.

In determining the airflow rate to dry the tomatoes, the following assumptions were made:

i. 10 hours of continuous operation to dry the product will be used.

ii. An ambient temperature of $30^OC$ ($T_1$)

iii. A chamber temperature of $45^OC$ ($T_2$)

iv. Density of air ($\rho$) at $T_2$ is $1.19kg/m^3$ (ITDG, 2002)

The mass flow rate is determined by:

$$Ma = \frac{Qu}{Cp\ (T_2 - T_1)} \quad \text{---------- (3.7)}$$

Where:

Ma = mass flow rate of air, Kg/s

Qu = useful energy gain flow rate, KJ/s

Cp = specific heat of air at $T_2$, $KJ/Kg^oC$

$T_2$ = Temperature of the drying air inside the dryer, $^oC$.

$T_1$ = ambient temperature $^oC$

$$Ma = 7.0 \frac{KJ}{s} \times \frac{1}{1.015.\frac{KJ}{Kg^o}} \times \frac{1}{(45^oC - 30^oC)} = 0.462 \text{ kg/s}$$

The volumetric flow rate of air at the drying section is

$$V = \frac{Ma}{\rho} \quad \text{---------- (3.8)}$$

Where: V = required volume air flow rate in the drying section

Ma = required mass airflow rate.

$\rho$ = density of air at $T_2$

$$V = 0.46 \frac{kg}{S} \times \frac{m^3}{1.19\ kg} = 0.387\ m^3/s$$

An existing centrifugal fan with eight blades in the department of Agric. Engineering ABU Zaria, which was evaluated and found to provide the required volume of air flow, was used for this research work

The measured speed of air produced by the fan through the inlet was 30km/hr. The area of the inlet (diameter 0.25m) is $0.0491m^2$, therefore the volumetric air flow rate = $0.491m^2$ x 8.33m/s = $0.409m^3/s$

### 3.4.6 **Determination of the Fan Shaft Diameter**

From equation 2.42 in section 2.6 the bending moment is given by:

$$M_b = \frac{W\ b}{12} \quad \text{---------- (3.9)}$$

The total distributed load on the blade W = 39.2 kN

The blade width, b = 0.2m

$$M_b = \frac{39200 \times 0.2}{12} = 653.68Nm$$

The torsional moment acting on a solid shaft, $M_t$ is given by:

$$M_t = \frac{KW \times 1000 \times 60}{2\pi\ rev/min} = \frac{9550 \times KW}{rev/min}$$ (Hall et al., 1980)

Where kW, is the engine output power = 4.41 kW

And the number revolution per minute of engine = 1120 rpm

$$M_t = \frac{9550 \times 4.41}{1120} = 37.60\ Nm$$

The shaft diameter is given by equation 2.45 in section 2.6

$$d^3 = \frac{16}{\pi S_S} \sqrt{(k_b M_b)^2 + (K_t M_t)^2} \quad \text{----------(3.10)}$$

From ASME code $k_b = k_t = 1.5$ and $\tau_m = 40MN/m^2$ (Hall et al., 1980)

$$d^3 = \frac{16}{3.14 \times 40 \times 10^6} \sqrt{(1.5 \times 653.68)^2 + (1.5 \times 37.60)^2}$$

d = 0.04996m

Therefore, the shaft diameter is 5cm.

### 3.4.6 Determination of the Fan Efficiency

The area covered by the rotation of one fan blade per one revolution of the fan is given by the area of the sector

$$\text{Area} = ½ \times 0.23^2 \times 0.7853 \times 8 = 0.168m^2$$

Therefore, volume of air swept by the rotation of the blades is:

$$\text{Volume} = 0.168 \times 0.14 = 0.02352m^3$$

The measured number of revolutions per minute of the fan is 1120rpm (18.66rps)

Total volume of air produced by the fan blades in one revolution is:

$$\text{Volume flow rate} = 0.0235 \times 18.66 = 0.448m^3/s$$

The fan efficiency ($\eta$):

$$\eta = 0.409/0.448 \times 100 = 91.2\%$$

## 3.5 Selection of Construction Materials

The materials used in the construction of the dryer were selected based on the normal farm structures selection criteria, namely; availability, culture, acceptability, economic cost, safety and strength of materials.

i. Mud block: Northern Nigeria is relatively dryer when climatically compared to the southern part of Nigeria. This has contributed to the successful usage of mud structures, which is not only economically viable but also very durable in this region if well constructed and protected. Researchers have also attributed some qualities of mud in terms of its high thermal capacity (El-Okene, 1995).

ii. Straw Mat (*Asabari*): Straw mat was chosen because of its availability in all the villages around the study area and it's relatively low in cost compared to the wire mesh. It equally has an advantage of not staining the tomatoes during drying as when compared with the wire mesh.

iii. Top cover: Transparent materials pose the greatest problem in construction of dryer. Glass is expensive and breaks easily therefore the material chosen as top cover was white transparent polythene, because is available and costs less when compared to glass. It can easily be replaced in case of tear and degradation**.**

### 3.6 Construction of the Dryer

**i.** Dryer chamber

The labourers from the villages around the market were employed to work on the construction of the dryer with close supervision.

The construction site was situated at the southern part closer to the main gate of the market. The dryer chamber was built using mud blocks, because of its high thermal capacity (El-Okene, 1995), its availability and use by the farmers in constructing their houses in the villages. Mud blocks each measuring 300 x 200 x 100mm were laid on the ground in the traditional way as the farmers used to do in building their houses. The length of the dryer chamber constructed was 30 metres and the width was 1.35 metres while the height was 0.7 metres as shown in Plate 3.1. The chamber was filled with sand up to 0.5 metres leaving a free board of 0.2 metres as shown in Plate 3.2. The walls and surface floor of the drying chamber were plastered and smoothened with a mixture of sand and water.

Air inlet and outlet were constructed at both ends of the chamber; the inlet measured 1.1m X 0.2m wide while the outlet measured 0.5m X 0.2m wide.

ii. Drying Trays

A straw mat (*Asabari*) commonly found in the villages around the study area, where it is used as a door blind was used as a drying tray. It was used because of its availability, does not stain the tomato as wire mesh does and costs less than wire mesh. The *Asabari* was brought from Kura, a village close to the study area. It was loosened and rearranged on a wooden frame measuring 200 x 100cm.

**iii**. Dryer Top Cover

White transparent polythene was used as a top cover, which is readily available in the market place in the villages around the study area. The top cover was constructed on a wood frame measuring 200 x 150 x 2 cm.

An engineering drawing of the forced convection solar dryer is shown in figure 3.2



PLATE 3.1 CONSTRUCTED DRYING CHAMBER
(Mud drying chamber is in front of house)



PLATE 3.2 CONSTRUCTED DRYING CHAMBER FILLED WITH SAND

## 3.7 Experimental Design

The treatments were randomly assigned in a 3x3x2 factorial experimental design with three drying methods i.e. forced convection, natural convection (closed chamber), natural convection (open chamber) as vertical treatments and two slice types i.e. local slice (A) and Eke's slice (B) as horizontal treatments, with measurement taken at three different point within the drying chamber. The drying trays were arranged in alternate based on the slice type on the bed as shown in figure 3.3.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Slice type A | Slice type B | Slice type A | Slice type B | Slice type A | Slice type B | Slice type A | Slice type B |

**Figure 3.3 Arrangement of drying trays on the drying chamber.**

The three different methods of drying were supposed to be run concurrently for proper evaluation, but due to the cost involved in the construction of the dryer, only one bed was constructed and the three different methods of drying were run consecutively with the assumption that the change in weather conditions will not have much effect on the conduct of the experiment.

## 3.8 Test Procedure

An eight blade radial flow, centrifugal fan (blower), driven by a 5.91hp (4.4kW) diesel engine was connected to the drying chamber. The blower together with the engine were bolted on the blower stand as shown in Plate 3.4. Air at ambient temperature enters the fan and flows out through the air connecting duct into the chamber through the air plenum. Drying trays (*Asabari*) supported on logs of wood were laid inside the drying chamber with the sliced tomatoes on the tray as shown in Plate 3.3, and transparent polythene on wood frame was used to cover the drying chamber.

UC-82B tomato variety was used in all the experiments, this variety of tomato is a firm, round-shape which is the common type grown by the farmers in most of the villages under the area of study. The physical properties of tomato is shown in Appendix

Baskets of tomatoes were bought from Kwanar Gafan Market. Each basket weighs about 40kg. It was then sorted, washed and slices into two different forms, the local slice type, where the tomato was cut into two halves along either the major or minor axis (type A) and the Eke's slice type, where tomato was cut into 10 to 15mm thickness along the minor axis, depending on the size of tomato (type B). Figure 3.4 shows the major and minor diameters of the tomato.

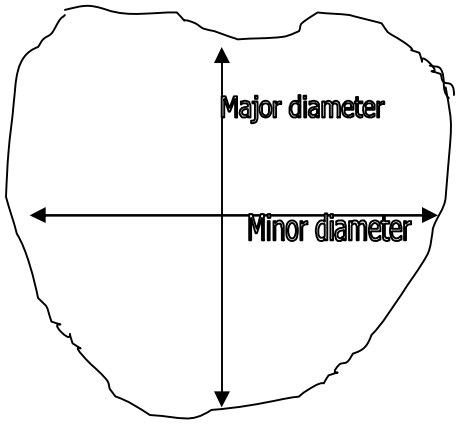



Figure 3.4. Sketch of tomato showing the major and minor diameters

Each type of slice was then placed on the drying trays (*Asabari*) and arranged in the drying chamber as shown in Plate 3.3. The dryer was covered with a polythene top cover as shown in Plate 3.5.

Similar samples of tomato were sliced and placed outside on the ground for open-sun drying in the same way the farmers do as shown in Plate 4.1, serving as controls.



PLATE 3.3 SAMPLES OF TOMATOES SPREAD ON DRYING TRAYS INSIDE DRYING CHAMBER.



PLATE 3.4 BLOWER (FAN) CONNECTED TO THE DIESEL ENGINE



PLATE 3.5 DRYER LOADED WITH SAMPLES OF TOMATOES AND COVERED WITH POLYTHENE DURING TEST.

During the process of drying, the samples from each drying systems were weighed at regular intervals of three hours daily, starting from 8.00am and ending by 6.00p.m. The drying is carried out until no further weight loss was recorded. The samples being dried were left in the dryer for the whole night with the cover removed to avoid condensation of vapour over night. The following morning weight of the samples was measured and recorded. The samples under going open sun drying system were covered with wire mesh by 6.00pm to prevent it from being eaten by rats over night.

Samples of tomatoes were taken for oven drying at the beginning of the experiment to determine the oven dry moisture content.

Throughout the duration of the drying processes, measurements were taken of the following parameters:

(a) Ambient temperature, relative humidity and air speed.
(b) Drying chamber temperature, relative humidity and wind speed
(c) Solar radiation
(d) Weights of sample

## 3.9 Instrumentation and Data Collection

Haenni Solar 118 Delta, a digital instrument with sensor output shown in Plate 3.6 was the instrument used to measure the total solar irradiance on the surface of the solar dryer.

Dry bulb and Wet bulb thermometers of range $0^0$F to $110^0$F as shown in Plate 3.7 left, was used to measure values of dry and wet bulb thermometer and the relative humidity read directly from the psychrometric chart.

A digital hand-held wind speed anemometer shown in Plate 3.7 right was the instrument used to measure wind speed.

Wang weighing balance with scale range of 0 to 50kg was the instrument used to measure the weight of tomato inside a basket. Another weighing balance of range 0 to 1200g was used to measure the weight loss of tomato samples.

A Brain weight B 500 digital top loading balance of range 0 to 500g with sensitivity of 0.001(10mg) was used to measure the weight of samples dried in the oven for moisture content determination in the laboratory. Shermond oven of model 2000 with temperature range of $10^0$C to $210^0$C was used in oven drying to obtain the bone dried moisture content of tomato samples at $70^0$C for a period of 8hr (Brenndorfer et al., 1987

Tomato moisture content was determined using the following formula:

$$MC_{wb} = W_m / W_o \times 100 \quad \text{.....(3.11)}$$

Where: $MC_{wb}$ = Moisture content, wet basis, %

$W_m$ = weight of moisture in the product, g

$W_o$ = initial weight of fresh tomato, g

The result of moisture content of tomato in oven dry was presented in Appendix E.

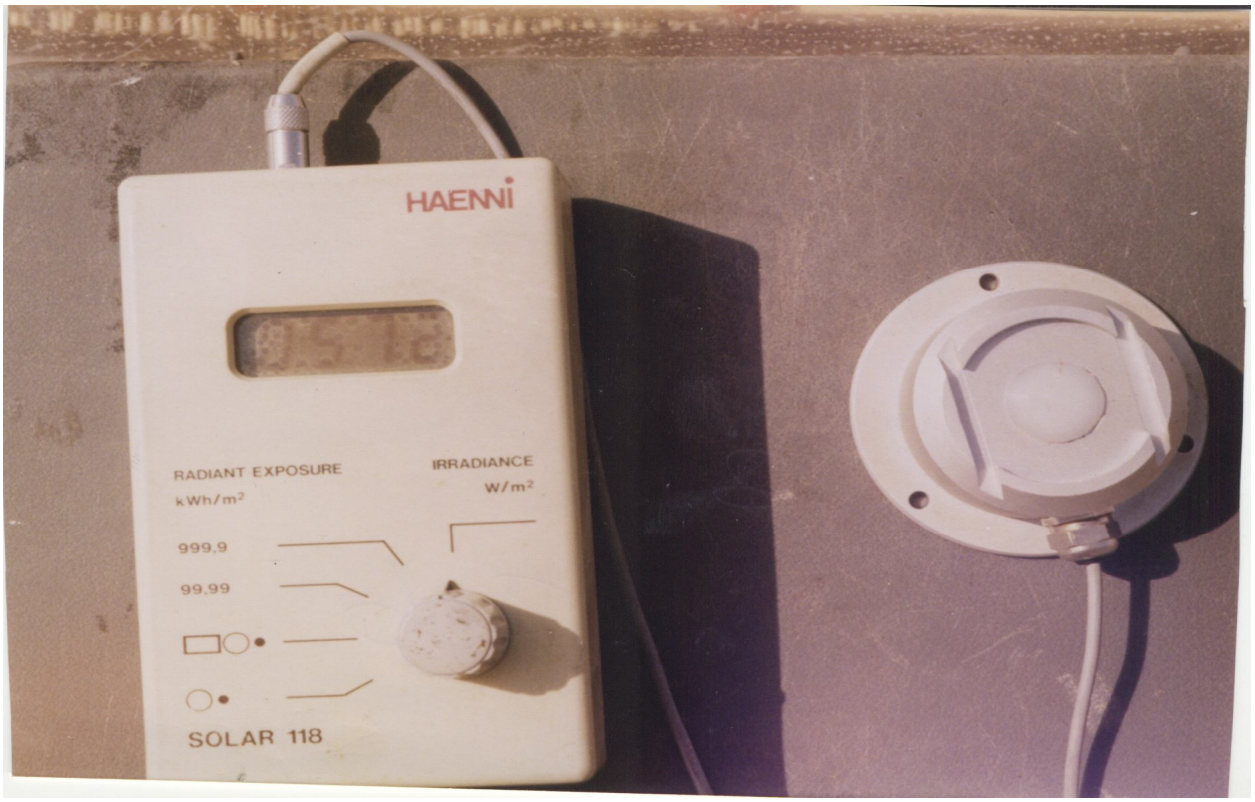



PLATE 3.6 HAENNI SOLAR 118 DELTA INSTRUMENT



PLATE 3.7 DRY BULB-WET BULB THERMOMETER AND HAND HELD ANEMOMETER

## 3.10 Organoleptic Test

In this research work attempts were made to determine the damage done to the dried tomato using colour and taste as indication for microbial activity. According to Moreau (1979) the more the microbial infestation the darker the food item.

### 3.10.1 Colour Test

Samples of dried tomatoes from the drying systems were exhibited to 5 randomly selected personnel in the department of Food technology Kaduna polytechnic. A grading colour code sheet of red which is the closest in relation to the colour of fresh tomatoes was used. The colour plate present different shades of red colour in the following format:

i. intense un-shaded red colour as: Lively

ii. A little shaded to deepen the red colour as: Deep

iii. Tones with dominant grey as: Sombre

iv. Moderate shading and intensity of red colour as: Dull

### 3.10.2 Flavour Test

Flavour test was carried out on the tomatoes samples from the drying systems using the same personnel as mentioned above to determine the degree of sourness.

The degree of sourness was graded under the following:

Very much sour.

Moderately sour.

Slightly sour.

Not sour.

# CHAPTER FOUR

## RESULTS AND DISCUSSION

### 4.1 INTRODUCTION

This chapter present the results of the work done, its analyses and discussion. The presentation is in three sections.

The first section presents the results obtained from the preliminary investigation with regards to the questionnaires administered to the farmers and professional local tomato dryers.

The second section presents results, analysis and discussion of the experiment carried out on drying tomatoes using the forced convection dryer constructed alongside the open-sun drying as a control. Also, results and discussion were presented for the natural convection in which the drying chamber was either closed or opened.

The third section presents results and discussion of the comparative evaluation carried out between the forced convection dryer, natural convection dryers (open and closed chambers) and open-sun drying (control) systems on drying tomatoes under the two different slice types.

### 4.2 Preliminary Investigation

#### i. General

The questionnaires (Appendix A-1, A-2) were administered to the farmers and the professional local tomato dryers by asking them the relevant questions by the researcher. Although some of the farmers were reluctant to give their names, thinking

that the information will be used for tax and levies purposes by the government, they were able to answer the questions either individually or in groups.

From the questionnaires, it was observed that, the average farming experience of the farmers interviewed range between 5 to 10 years, while 90% of the farmers have a land holding of less than 2 hectares, placing them as small-scale farmers going by Ijere (1986) classification of Nigerian farmers. It was observed that, 85% of the farmers interviewed cultivate their farmland using tractor. They hired the tractors either from individuals or government agricultural agencies likes, Hadejia-Jama'are River Basin Development Authority (HJRBDA), Kano Agricultural and Rural Development Authority (KNARDA), state ministry of agriculture and the local government authorities. However, all other farm activities like planting, weeding, fertilizer application and harvesting are carried out using human labour.

The professional dryers are those farmers and individuals that are involved in drying tomatoes on commercial basis. They moved from one tomato producing area to another during the harvesting period for the purposes of buying and drying tomatoes in the areas.

It was observed from the interview that most of the professional local tomato dryers have years of experience ranging between 6 to 10 years in drying business. They dried between 150kg to 280 kg (4 to 7 baskets) of tomatoes per batch per person.

**ii. Cropping Culture**

It was also observed that 70% of the farmers interviewed plant tomato alongside with other crops like maize, onion, pepper, carrot, watermelon and other vegetables, while 30% plant tomato alone during dry season farming.

### iii. Production of Tomato.

Different varieties of tomato were planted within the study area. The varieties include Roma VF, UC 82 B and local variety (*Dan Kasa*) but, 85% of the farmers interviewed plant UC 82 B mainly because of some of its salient features of maturing early (125 days), firmness and good storage quality (Pioneer 2004).

It was observed that the farmers' production level of tomato ranged between 100 to 6000 baskets on a farmland area of 0.4 to 8 hectares respectively.

iv. Preservation and Marketing of Tomato.

The farmers sell most of the tomato they produce and keep some for their consumption. The ones that are kept for consumption are either preserved by keeping them inside basket for a period of not more than 10 days or they are sliced along the major axis and spread on the roadside for open-sun drying.

Farmers sell a basket of fresh tomato weighing about 38 to 40kg at a price that ranged between ₦200 to ₦1000 depending on its availability and quality. It was also observed that most of the farmers are into tomato production because of the income they generate from the sell of the crop as shown in table 4.1.

**Table 4.1:Production of Tomato and Hectares of Cultivation for the Dry Season under Kadawa River Project**

| SEASON | AREA CROPPED (HA) | PRODUCTION (MT) | VALUE OF PRODUCE (₦ MILLION) |
|---|---|---|---|
| 1993/94 | 1,300.56 | 46,500.00 | 441.75 |
| 1994/95 | 1,602.85 | 75,000.00 | 750.00 |
| 1995/96 | 1,796.61 | 94,322.00 | 741.00 |
| 1996/97 | 2,050.00 | 120,000.00 | 1,200.00 |
| 1997/98 | 1,232.68 | 45,301.00 | 407.71 |

**SOURCE:HJRBDA,2003.**

**(v) Drying Process of Tomato.**

The process of drying tomato as explained by the professional dryers involves:

♦ Procurement: buying low-grade tomato (rotten or damaged types of tomatoes called *Bage*) that cost less than the good or high-grade tomato called *Kauda.*

♦ Slicing: the tomato is sliced into two along the major axis.

♦ Spreading: the tomato is spread on the ground normally by the roadside (see Plate 4.1) for open-sun drying, and is allowed to stay for about 4 to 5 days.

♦ Turning: it is then turned and allowed to stay for another 3 to 5 days depending on the weather conditions.

♦ Cleaning: when it has dried, the tomato is packed (see Plate 4.2) and cleaned using a perforated metal or basket container by shaking to removed stones and debris.



PLATE 4.1 FRESH SLICED TOMATOES SPREAD ON THE GROUND BY THE FARMERS FOR OPEN-SUN DRYING.



PLATE 4.2 PROFESSIONAL DRYERS SEEN SPREADING AND PACKING SOME OF THE DRIED TOMATOES AT THE MARKET.

(vi) Packaging and Marketing of Tomato.

Dried tomatoes are bagged into either a jute or polythene bag for storage. After bagging it's either sold in mudu (metal bowl measure) at a cost ranging from ₦70 to ₦100 or in a bag at cost ranging from ₦2500 to ₦2700.

## 4.3 Centrifugal Fan (Blower) Evaluation

The centrifugal fan was evaluated under no load condition to determine the volumetric air flow rate at three different points**.**

TABLE 4.2 Result of Centrifugal Fan Evaluation

| Engine rpm | Air volume flow rate $m^3s^{-1}$ | | |
|---|---|---|---|
| | P1 | P2 | P3 |
| 780 | 0.28 | 0.20 | 0.09 |
| 682 | 0.22 | 0.16 | 0.05 |
| 650 | 0.17 | 0.10 | 0.08 |

P1=1m away from fan inlet; P2=10m away from inlet; P3=25m away from inlet

The result shows a decreasing air flow rate with an increase in distance from the fan inlet in the drying chamber. This may be due to the loss of air from the dryer through top cover that was observed during the test. Also there was decrease in air flow rate with decrease in engine number of revolution per minute (rpm). It was observed during the test that when the engine number of revolution per minute increased to 800rpm, the dryer top covers were blown up.

## 4.4 Cutting Time of Tomato Slices

The slicing time of tomato during the experiment was determined for the two types of slice (Local and Eke's). It was observed that the average cutting time for 1kg of tomato using local slice type was 1 minute, while the average cutting time for 1kg of tomato using Eke;s slice was 2.5 minutes. The cutting time depends on factors like experience and the quantity involved, because, the person cutting may retard due to tiredness thereby affecting the next slice cut. This shows that Eke's slice requires more time which increases the labour cost.

## 4.5 Results of Evaluation of On-site Dryers.

Detailed tabulated data of drying performance of the forced convection tomato solar dryer, natural convection (closed and open chamber) tomato solar dryers during the batch were shown in Tables B-1, B-2 and B-3 respectively in appendix B.

**TABLE 4.3 Summary of the Result of Drying Local and Eke's Sliced Tomato under Four different Drying Methods**

| Drying Method | Initial moisture content, w.b % | | Final moisture content, w.b % | | Duration of drying, days | |
|---|---|---|---|---|---|---|
| | L | E | L | E | L | E |
| Forced convection | | | | | | |
| P1 | 92.5 | 92.5 | 7.2 | 7.2 | 4 | 1.5 |
| P2 | 92.5 | 92.5 | 7.2 | 7.3 | 3 | 2 |
| P3 | 92.5 | 92.5 | 7.0 | 7.2 | 3.5 | 2 |
| Natural convection closed chamber | | | | | | |
| P1 | 92.5 | 92.5 | 7.5 | 7.2 | 5 | 3 |
| P2 | 92.5 | 92.5 | 7.3 | 7.4 | 5.5 | 4 |
| P3 | 92.5 | 92.5 | 7.4 | 7.4 | 6 | 3 |
| Natural convection open chamber | 92.5 | 92.5 | 7.4 | 7.5 | 6 | 4 |
| Open sun | 92.5 | 92.5 | 7.5 | 7.4 | 7 | 4 |

L= Local sliced tomato: E= Eke's sliced tomato; P1= A1 or C1, P2= A2 or C2, P3 =A3 or C3 were distance of drying trays from inlet as shown in Appendix B.

### 4.5.1 Effect of Tomato Sliced Type and Drying Method on Drying Period

From the summary of the result in Table 4.3 above, it was observed that local and Eke's sliced tomatoes dried at different time under the four drying methods. Eke's sliced tomato generally dried faster than local sliced tomato. In forced convection solar dryer Eke's sliced tomato dried in 2 days while local sliced tomato dried in 4 days. In natural convection (closed chamber) solar dryer, Eke's

sliced tomato dried in 3.5 days as compared to 6 days in local sliced tomato. In natural convection (open chamber) solar dryer, Eke's sliced tomato dried in 4 days as compared to 6 days in local sliced tomato. Samples of Eke's tomatoes in open sun dryer dried in 4 days while the local sliced tomatoes dried in 7 days.

The variation in drying period between the slice types of tomatoes could be due to the reduction in thickness and cut surfaces of Eke's sliced tomato which facilitated the evaporation of moisture faster than in local sliced tomato where the thickness is more and only one surface was cut.

The variation in drying period with respect to the drying methods could be due to the use of fan in the case of forced convection solar dryer which facilitated the evacuation of evaporated moisture in the drying chamber as when compared to the other drying system where fan was not used. Also lower relative humidity and higher temperature recorded in the drying chamber of forced convection dryer as when compared with the ambient condition made the forced convection solar dryer to dry tomatoes faster than the other systems.

### 4.5.2 Effect of Drying Tray Distance from the Blower on Drying Rate in Forced Convection Solar Dryer

Figure 4.1 shows the drying rate curves of the local sliced tomatoes in both forced convection dryer at different positions of tomatoes in the drying chamber from the blower and the open sun drying system (control).

The drying rate curves show that, there was decrease in drying rate from initial moisture content to the final moisture content for the tomatoes placed at different positions in the drying chamber, although at initial stage of the curves when moisture

content was high (92.5% w.b), the drying rate was higher in position $A_1$ compared to $A_2$, $A_3$ and B ($A_1 > A_2 > A_3 > B$) but at the lower end when the moisture content reduces, the characteristics of the drying rate curves change with tomatoes in positions $A_2$ and $A_3$ having higher drying rate compared to $A_1$ and B, ($A_2 > A_3 > A_1 > B$). This could be due to the fact that, in the initial stage when moisture was high, evaporation was also high, because less energy is required to evaporate the moisture from the surface of the tomato. When the free moisture on the surface has evaporated, more energy is required for internal moisture migration to the surface for evaporation. This required high temperature and low relative humidity.

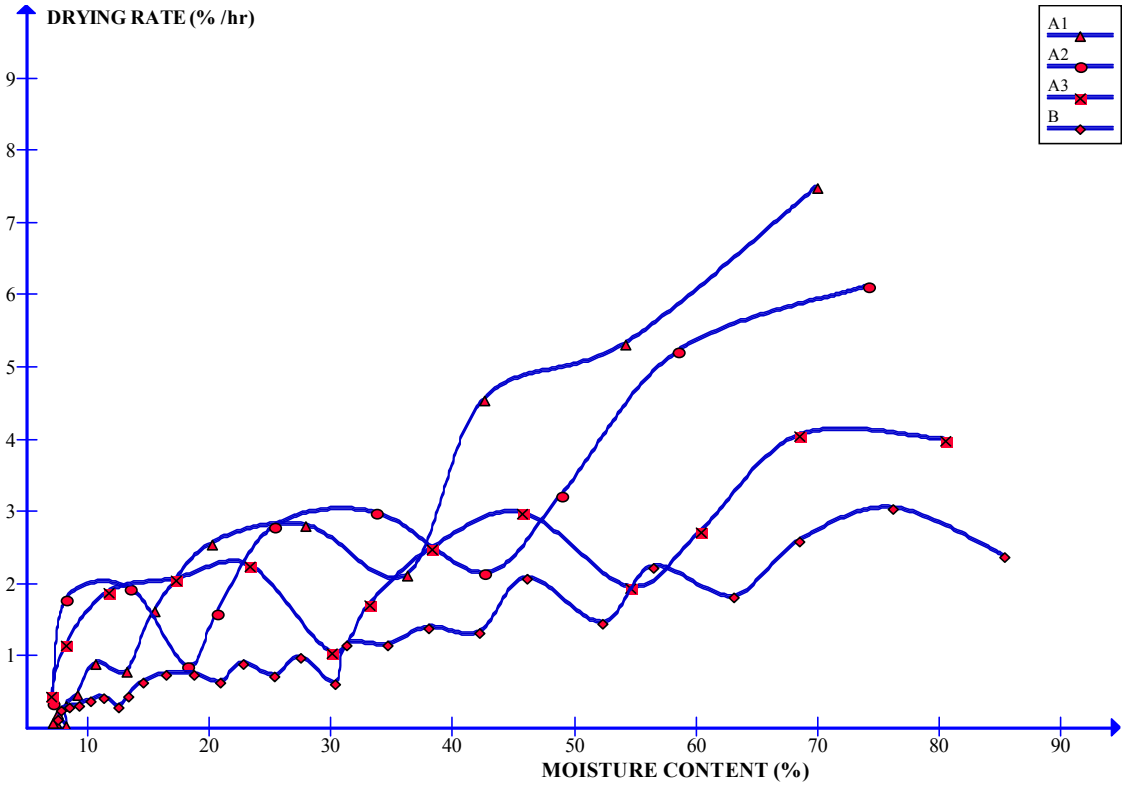



**FIG.4.1 Drying Rate Curve for Forced Convection Solar Dryer (Local Sliced Tomato)**

**(A1 = Sliced tomato at 1m from inlet; A2 = Sliced tomato at 10m from inlet; A3 = Sliced tomato at 22m from inlet; B= Sliced tomato in open sun)**

Statistical analysis using ANOVA showed in Table 4.4 that there was significant difference at $P \leq 0.05$ level of significant for the positioning of tomatoes within the drying chamber and also with the control. Least significant difference test (LSD) also

shows that, position $A_2$, was better than $A_3$ and $A_3$ was better than position $A_1$, when compared with B (control) at $P \leq 0.05$ level of significant.

**Table 4.4: Analysis of Variance (ANOVA) of the effect of drying tray distance of local sliced tomatoes on the drying rate in forced convection solar and open sun dryers.**

| Source of Variation | Sum of squares | D.F | Mean square | $F_{CALCULATED}$ | $F_{TABLE}$ at 5% 1% |
|---|---|---|---|---|---|
| Position | 23.53 | 3 | 7.84 | 3.66* | 2.76 4.13 |
| Error | 132.81 | 62 | 2.14 | | |
| Total | 156.34 | 65 | | | |

*= Significant at 5% level

Figure 4.2 shows the drying rate curves of the Eke's sliced tomatoes in forced convection solar dryer and open sun drying system.

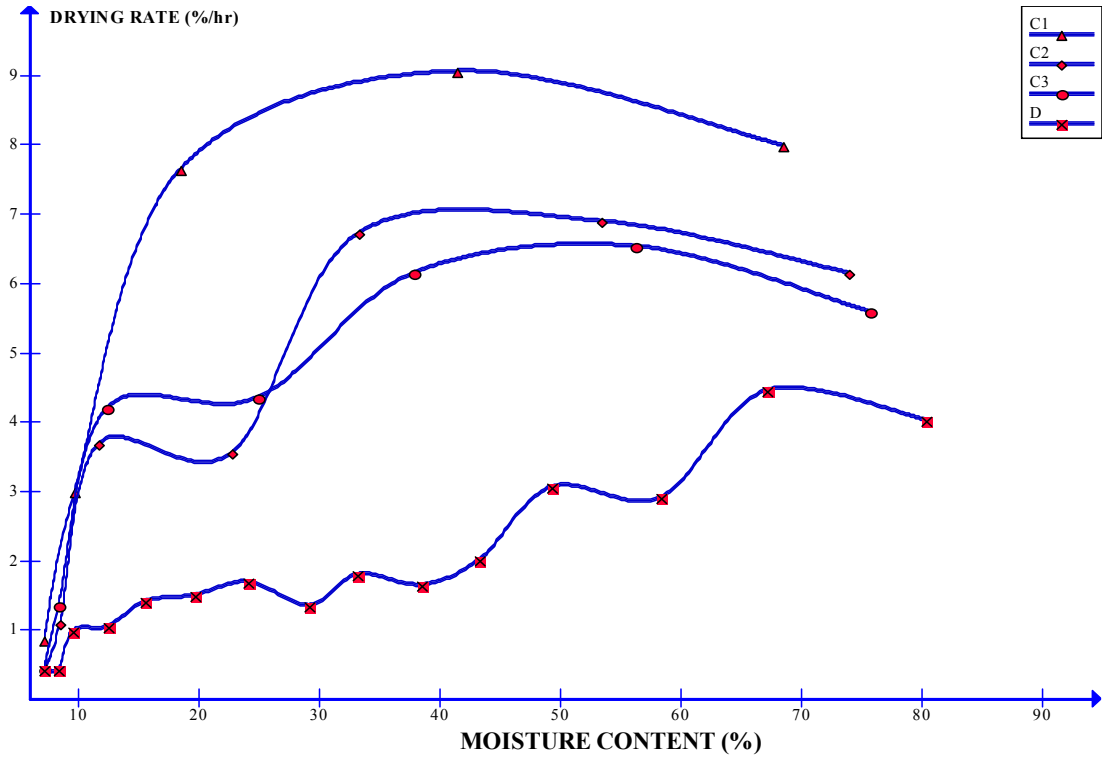



**FIG. 4.2. Drying Rate Curve for Forced Convection Solar Dryer (Eke's Sliced Tomato)**

**(C1 = Sliced tomato at 2.5m from inlet; C2= Sliced tomato at 12m from inlet; C3 = Sliced tomato at 20m from inlet; D = Sliced tomato in pen sun)**

The drying rate curves show that positions of tomatoes in the drying chamber affect the drying rate. Tomatoes in position $C_1$ had the highest drying rate and dried faster than all others in different positions. Tomatoes in position $C_2$, dried faster than $C_3$ but less than position $C_1$, while D (control) had the least drying rate. This could be due to the fact that samples in position $C_1$ were closer to the blower and therefore received more air that hastened the evaporation of moisture from the product than the other positions. Also the differences in temperature and the relative humidity between the drying chamber and the ambient condition caused the samples of tomato in the drying chamber to dry faster than the control. Thickness of Eke's sliced tomato was less when compared with local sliced tomato therefore the former dried faster than the local sliced tomato.

Analysis of variance in Table 4.5 shows there was a high significance difference due to positioning at $P \leq 0.01$ significant levels of Eke's sliced tomatoes.

The least significant difference (LSD) test between the means of positions $C_1$,$C_2$ and $C_3$ shows that there was no significant difference. However, the LSD test shows that there were significant differences between the means of $C_1$,$C_2$ and $C_3$ when compared with the D(control).

**Table 4.5: Analysis of Variance (ANOVA) of the effect of drying tray distance of Eke's sliced tomatoes on the drying rate in forced convection solar and open sun driers.**

| Source of Variation | Sum of squares | D.F | Mean square | $F_{CALCULATED}$ | $F_{TABLE}$ at 5% | 1% |
|---|---|---|---|---|---|---|
| Position | 66.06 | 3 | 22.02 | 4.51** | 2.92 | 4.50 |
| Error | 146.42 | 30 | 4.88 | | | |
| Total | 212.47 | 33 | | | | |

**= Highly significant at 1% level

### 4.5.3 Effect of Drying Tray Distance on the Drying Rate of Tomato in Natural Convection (closed chamber) Solar Dryer

The drying rate curves of tomato samples in natural convection (closed chamber) are shown in Figure 4.3. It showed that the drying rate of local sliced tomatoes in position $A_1$ was relatively higher than in position $A_2$, and position $A_2$ was higher than positions $A_3$ and B (control). The control (B) has the lowest drying rate.

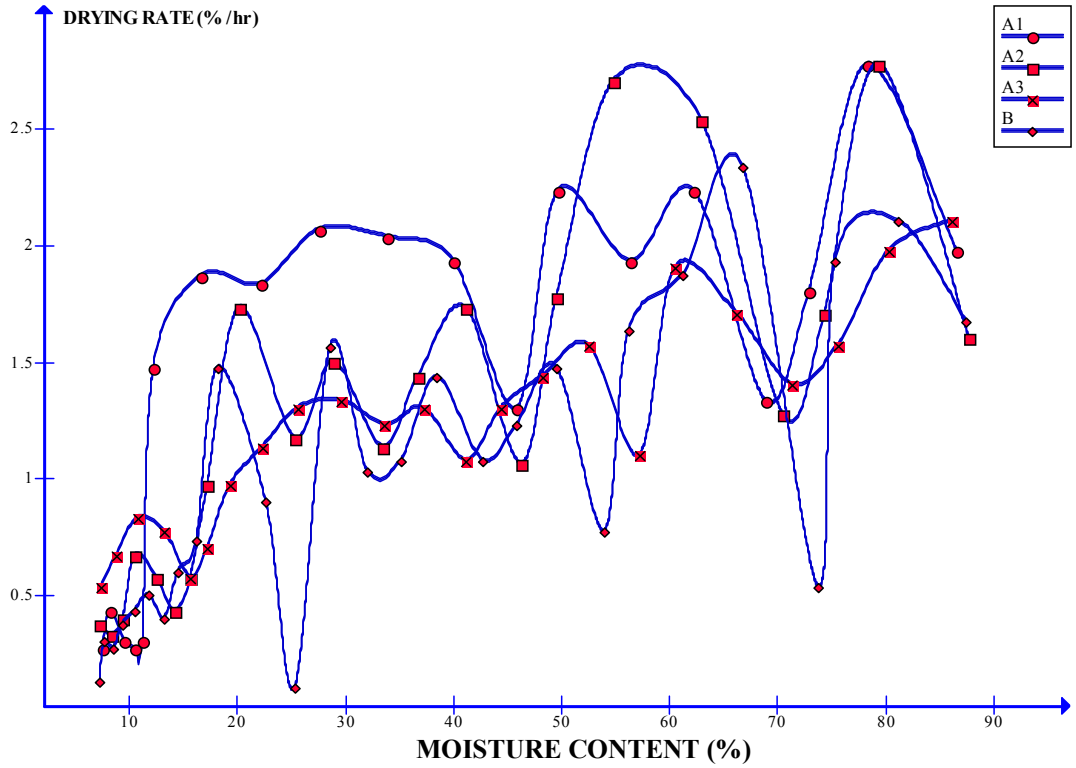



**FIG. 4.3 Drying Rate Curves for Natural Convection Closed Chamber Solar Dryer (Local Sliced Tomato)**

**(A1= Sliced tomato at 1m from inlet; A2= Sliced tomato at 14m from inlet; A3= Sliced tomato at 27m from inlet; B= Sliced tomato in open sun)**

The drying rate curves in figure 4.4 showed that the drying rate of Eke's sliced tomatoes in position $C_1$ was higher and dried faster than tomatoes in positions $C_2$, $C_3$ and D (control), while $C_3$ have higher rate than $C_2$ and D (control). The control (D) has the lowest drying rate when compared with samples in the drying chamber

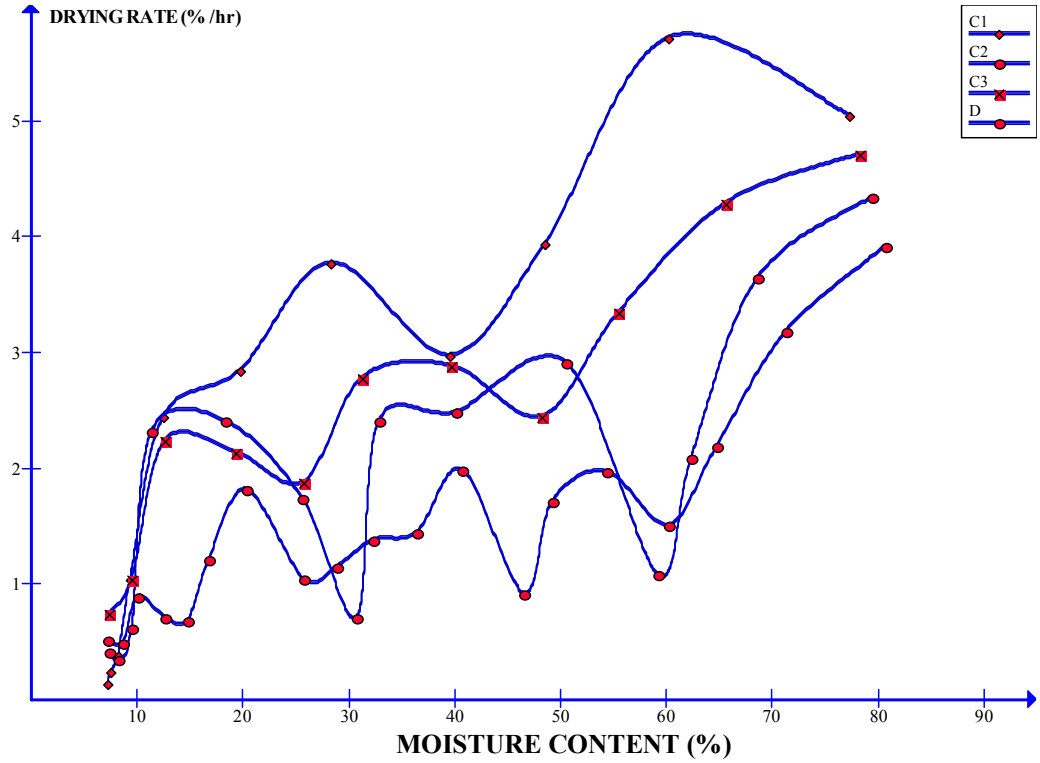



**FIG. 4.4 Drying Rate Curves for Natural Convection Closed Chamber Solar Dryer (Eke's Sliced Tomato)**

**(C1= Sliced tomato at 3m from inlet; C2= Sliced tomato at 16m from inlet; C3= Sliced tomato at 29m from inlet; D= Sliced tomato in open sun)**

The rate of drying as explained above differ between samples of the same sliced type because, drying trays that are closer to the opened ends of the dryer received more air than trays at inner part of the dryer. High temperature inside the chamber cause samples to dry faster than the control. The difference in drying rate between the sliced types could be because of the thickness in size and the open surfaces of the Eke's slice where air moves freely to evaporate the moisture faster than the local sliced type.

Analysis of variance (Table 4.6 below) shows that there is no significant difference at $P \leq 0.05$ significant level between the mean drying rates of tomatoes due to positioning of samples within the drying chamber and also with the control.

**Table 4.6: Analysis of Variance (ANOVA) of the Effect of Positioning of Local Sliced Tomatoes in Natural Convection (Closed Chamber) Solar and Open sun driers.**

| Source of Variation | Sum of squares | D.F | Mean square | $F_{CALCULATED}$ | $F_{TABLE}$ at 5% |
|---|---|---|---|---|---|
| Position | 1.73 | 3 | 0.58 | 1.32 ns | 2.76 |
| Error | 38.69 | 87 | 0.44 | | |
| Total | 40.42 | 90 | | | |

ns=Not significant

The analysis of variance at $P \leq 0.05$ significant level shown in Table 4.7 below, shows there is no significant difference between the mean drying rate of Eke's sliced tomatoes due positioning within the drying chamber and with the control.

**Table 4.7: Analysis of Variance (ANOVA) of the Effect of Positioning of Eke's Sliced Tomatoes in Natural Convection (Closed Chamber) Solar and Open sun driers.**

| Source of Variation | Sum of squares | D.F | Mean square | $F_{CALCULATED}$ | $F_{TABLE}$ at 5% |
|---|---|---|---|---|---|
| Position | 11.99 | 3 | 3.99 | 2.31 ns | 2.80 |
| Error | 88.28 | 51 | 1.73 | | |
| Total | 100.27 | 54 | | | |

ns= Not significant

Figure 4.5 shows the drying rate curves for both local and Eke's sliced tomatoes on the natural convection (open chamber) and the open sun solar dryers. The drying rate was higher at high moisture content and reduces to lower rate toward the safe storage moisture content. The drying rates of Eke's sliced tomatoes are higher than the local sliced tomatoes and dried faster. This could be because of the thickness of Eke's sliced that was less than the local sliced tomato. The drying curves show no clear differences

between the local sliced tomatoes on the drying chamber (A) and the control (B) also Eke's sliced tomatoes on the drying chamber (C) show less variation in drying rate with the control (D).

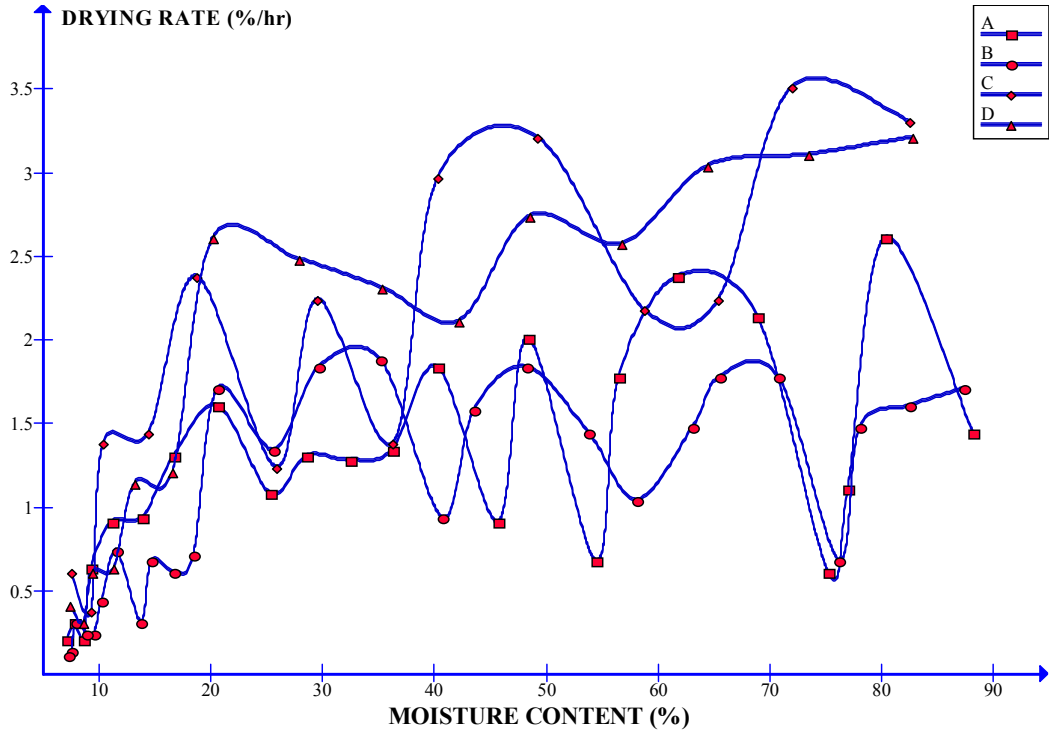



**FIG 4.5 Drying Rate Curves for Natural Convection Open Chamber Solar Dryer(Local and Eke's Sliced Tomato)**

**(A= Local sliced tomato in open drying chamber; B= Local sliced tomato in open sun; C= Eke's sliced tomato in open drying chamber; D= Eke's sliced tomato in open sun)**

## 4.6 Determination of Dryer Efficiencies

The related drying efficiencies calculated are: -

i. System Drying Efficiencies.

ii. Collector (Dryer) Efficiencies.

iii. Pick-up Efficiencies.

### 4.6.1 System Drying Efficiencies

The average daily insulation ($I_c$) incident on the collector was determined from the data collected during the crop drying; to be 473.36 $Wm^{-2}$. The latent heat of vaporization ($L_v$) of water is 2326000 $Jkg^{-1}$ at 40 $^0C$ (Brenndorfer et al., 1987).

The system drying efficiencies of the dryers are calculated using equation (2.47) as follows:

When 300kg of local sliced tomato at 92.5% initial moisture content, wet basis was dried using forced convection dryer to 7.2% moisture content, wet basis in an average of 4 days.

Thus: $$\eta_d = \frac{M_w L_v}{I_c A_c t}$$

But

$$M_w = \frac{(MC_{id} - MC_{fd})}{100} X \ D_m$$

$$D_m = W_P - W_p MC_{iw}$$

Where: $D_m$ = Bone dry weight of tomato

$MC_{iw}$ = initial moisture content (decimal)

$D_m = 300 - 300 \text{ X } 0.925 = 22.5$ kg

$$MC_{id} = \frac{92.5}{100 - 92.5} = 12.33\%$$

$$MC_{fd} = \frac{7.2}{100 - 7.2} = 0.077\%$$

$$M_w = \frac{(12.33 - 0.076)}{100} \text{ x } 22.5 = 275.75 \text{ kg}$$

The effective dryer area ($A_c$) is $30m^2$

t = 4 days of 10 hours of effective daily drying.

i.e. t = 4 x 10 x 3600 = 144000 sec.

Substituting the values in equation 3.1

$$\eta_d = \frac{275.75 \text{ x } 2326000 \text{ x } 100}{473.36 \text{ x } 30 \text{ x } 144000} = 31\%$$

Following the above method of calculating system drying efficiency from the data collected during the drying processes, the value in Table 4.7 are generated for different dryers tested.

**Table 4.8: System Drying Efficiencies ($\eta_d$) of Dryers**

| Drying System | Slice Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| FC | Local | 300 | 22.50 | 277.50 | 30 | 144000 | 92.5 | 7.2 | 31 |
| | Eke's | 150 | 11.25 | 138.75 | 30 | 72000 | 92.5 | 7.2 | 31 |
| NCCC | Local | 300 | 22.50 | 277.50 | 30 | 216000 | 92.5 | 7.4 | 23 |
| | Eke's | 150 | 11.25 | 138.75 | 30 | 108000 | 92.5 | 7.4 | 23 |
| NCOC | Local | 300 | 22.50 | 277.50 | 30 | 216000 | 92.5 | 7.2 | 22 |
| | Eke's | 150 | 11.25 | 138.74 | 30 | 144000 | 92.5 | 7.3 | 17 |
| OS | Local | 300 | 22.50 | 277.50 | 30 | 252000 | 92.5 | 7.4 | 18 |
| | Eke's | 150 | 11.25 | 138.75 | 30 | 144000 | 92.5 | 7.2 | 16 |

FC = Forced Convection Dryer.

NCCC= Natural Convection Closed Chamber Dryer.

NCOC= Natural Convection Open Chamber Dryer.

OS = Open Sun Dryer.

1 = Weight of tomatoes before drying, kg

2 = Weight of dry matter ($D_m$), kg

3 = Weight of water removed, kg

4 = Effective dryer area ($A_c$), kg

5 = Drying time (t), s

6 = Initial moisture content wet basis, %

7 = Final moisture content wet basis, %

8 = System drying efficiency, %

### 4.6.2 Collector Efficiencies ($\eta_c$)

The volumetric flow rate of air through an air plenum of 5mm height and 1.3m length of the air duct and with an average air speed of 7.33m $s^{-1}$ through the drying chamber in forced convection dryer is calculated using equation (2.48) as follows:

$$\eta_C = \frac{v.\ \rho.\ \Delta T.\ C_P}{A_C\ I_C}$$

$v = 0.005 \times 1.3 \times 7.33 = 0.48 m^3 s^{-2}$

$\rho = 1.23$ kg $m^{-3}$

$C_p = 1004$ J $kg^{-1}\ ^0C^{-1}$

$A_c = 30m^2$

$I_c = 473.36$ W $m^{-2}$

$\Delta T = (42 - 38) = 4\ ^0C$

Substituting the above values into equation 3.4.

$$\eta_C = \frac{0.48 \times 1.23 \times 4 \times 1004}{30 \times 473.36} \times 100 = 17\%$$

For natural convection closed chamber dryer,the volumetric flow rate of air through the drying chamber is:

$$0.26 \times 1.33 = 0.35 m^{-3} s$$

The average dryer chamber and the ambient temperatures are 43.3 $^0C$ and 39.7 $^0$ C respectively.

$\Delta T = (43.3 - 39.7) = 3.6\ ^0C$

$$\eta_C = \frac{0.35 \times 1.23 \times 3.6 \times 1004}{30 \times 431} \times 100 = 12\%$$

### 4.6.3 Pick-up Efficiencies ($\eta_p$)

This is expressed by the formula as shown in equation (2.49):

$$\eta_p = \frac{M_o - M_t}{v\ .\ \rho\ .\ t\ .\ (h_{as} - h_i)} \ldots$$

In case of forced convection solar dryer.

$M_w$ = 275.75 kg , V = 0.48 $m^3 s^{-1}$, $\rho$ = 1.23 kg $m^{-3}$

t = 4 x 10 x 3600 = 144000 sec

$h_{as}$ and $h_i$ are calculated using the psychrometric chart.

$h_i$ at 38 $^0$C and 38% R.H is 0.0176 kg $kg^{-1}$, $h_{as}$ is also found from psychrometric chart by following a line of constant humidity from $h_i$ to its intercept with 40 $^0$C line and then along the line of constant enthalpy to its intercept with the 100% saturation curve, giving a value of 0.023 kg $kg^{-1}$

Substituting the values into equation (2.49)

$$\eta_p = \frac{275.25 \quad x\ 100}{0.48 \times 1.23 \times 144000 \times (0.023 - 0.0176)} = 58\%$$

Following the same method of calculations as shown above, the pick-up efficiency of natural convection closed chamber dryer is as follows:

$h_i$ at 40 $^0$C and 40% R.H is 0.0196, $h_{as}$ = 0.0258 from the psychrometric chart.

The average wind speed is 0.35m $s^{-1}$ and the drying time, t is 216000 sec.

$$\eta_p = \frac{275.25 \ x\ 100}{0.35 \times 1.23 \times 21600 \times (0.0258 - 0.0196)} = 46\ \%$$

i, System Dying Efficiency: The system drying efficiency of the forced convection solar dryer was higher than the other drying systems for both local and Eke's sliced tomatoes, this may be due to the fact that the drying period for the forced convection dryer was less compared to the other systems. Moreover, the drying period is inversely proportional to the system drying efficiency since other parameters were same.

ii, Collection Efficiency: The determined collector efficiency of the forced convection solar dryer was 17% and the natural convection closed chamber solar dryer was 12%,

the difference might be due to the fact that the volumetric air flow rate in forced convection dryer was higher than the natural convection closed chamber dryer.

iii, Pick-up Efficiency: The determined pick-up efficiency of the forced convection solar dryer was 58% and that of the natural convection closed chamber was 46%. The higher percentage value of the forced convection solar dryer might be due to the fact that the drying period was less when compared with natural convection closed chamber dryer.

### 4.7 Organoleptic Test

The quality test based on colour retention of dried tomato samples under the different drying systems is presented in the following table:

**Table 4.9 Organoleptic Test.**

| Samples | Colour | Flavour |
|---|---|---|
| Fresh tomatoes | Lively | Slightly sour |
| Forced convection dryer | Lively | Very much sour |
| Natural convection closed chamber | sombre | Not sour |
| Natural convection open chamber | Deep | Moderately sour |
| Open sun dryer | sombre | Moderately sour |

Samples of dried tomato under the forced convection solar dryer were observed to have an intense un-shaded red colour similar to the fresh tomato, while samples under natural convection dryers and open sun dryer were observed to have deep and sombre red colour respectively. The shaded red colour and the darkening of the samples might be due to the presence of micro-organism as reported by Moreau (1979).

The flavour test indicate that samples of tomato dried under the forced convection solar dryer had very much sour test, this could be due to the high concentration of ascorbic acid as a result of moisture evaporation and less period of drying. There was no sour test in samples of tomato dried under the natural convection closed chamber this might be due to high temperature recorded in natural convection closed chamber solar dryer and the long period of drying. Ascorbic acid is water soluble and is rapidly destroyed by heat as reported by Ladan et al. (1997), also dried tomato sample contained high ascorbic acid than fresh tomato as shown in table of nutrient composition of tomatoes in Appendix D.

## 4.8 COST ANALYSIS

The detailed breakdown of the cost of the constructed dryer, blower (Fan) and the diesel engine for the forced convection solar dryer are contained in Appendix C. The total estimated cost of production of the dryer is ₦ 60,850.

The variable cost includes the cost of tomato, fuel and engine oil, and labour.

Cost of 400kg (10 baskets) of tomato is ₦ 300 X 10 =₦ 3000

Cost of fuel/engine oil is ₦ 250 X 4.5 gallons X 4 days = ₦ 4500

Labour cost = ₦ 500.

Total fixed cost + variable cost = ₦ 60850 +₦3000 + ₦4500 + ₦300 = ₦ 68,650

# CHAPTER FIVE

## 5. CONCLUSIONS AND RECOMMENDATIONS

### 5.1 CONCLUSION.

Large size forced convection, natural convection closed chamber and natural convection open chamber tomato solar driers were successfully designed and constructed. The field experimental results showed that the performance of the forced convection tomato solar dryer was very encouraging when compared to open sun traditional drying method. Fifty percent saving in drying time was achieved for both local and Eke's sliced tomato types with forced convection dryer when compared with the traditional open sun drying method.

The slicing time for Local slice tomato was faster and requires less area but took more time to dry as when compared with Eke's slice where the slicing time is more and requires large area but it dry faster. This shows that the two slice types have one advantage that out weight that of the other.

Eke's sliced tomatoes dried faster than the local sliced tomatoes in both the drying systems. It was observed that within the drying period, the products generally increased slightly in moisture content over the night, which might be due to the fact that in the night generally the temperature was low and the relative humidity was high which result in condensation of moisture on the products.

The natural convection closed chamber dryer recorded the highest drying chamber temperature although there was no fan to hasten the removal of the moisture from the drying chamber.

Because of the drying trays where air can circulate both beneath and on top, the drying processes are faster in the other drying systems than the open sun (traditional) drying method.

Arrangement of the drying trays within the drying chamber did not show any change in the drying period of the tomatoes in all the drying systems as was observed during the first batch of the experiments.

The aim of locating the research work to the village where tomatoes are grown was to show the farmer how to construct the dryer with locally available and affordable materials and to test and show how the dryer works.

## 5.2 RECOMMENDATION

The mud-type structure of the dryer can be improved for better performance by plastering the walls with the mixture of sand and cement to avoid the collapse of structure during raining season or the drying structure can be constructed with cement blocks.

The polythene cover was found to be soft and it tore or punctured easily. Its transparency diminished with time even when it was cleaned, therefore it should be changed from time to time or the farmers should be encouraged to use white transparent plastic or glass if they can handle it with care.

The process of drying can be made to be continuous rather than in batch, since there are variations in drying time within the chamber of the forced convection solar dryer.

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APPENDIX A-1

# FACULTY OF ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING

A.B.U. ZARIA.

## QUESTIONNAIRE. A

DATE.....

LOCATION.....

STAFF.....

## TO: TOMATO FARMERS.

| | Respondent | Years of Farming Experience | Farm Land Size | Qty. of Baskets Produced | Labour Type | | | | Market Price per basket | | Presser-vation Method | Seed source & variety | | Source of water |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Cult. | Plant. | Weed. | Havst. | Fresh | Dry | | Govt. | Market | |
| | | | | | | | | | | | | | | |

**APPENDIX A-2**

# FACULTY OF ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING

A.B.U. ZARIA.

## QUESTIONNAIRE. B

DATE……

LOCATION……

STAFF……

## TO: PROFESSIONAL TOMATO DRYERS.

| S/NO | Respondent | Years of Experience in drying business | Qty.of fresh tomato dried per batch | Qty.of dried tomato obtained per batch | Preservation method | Ave. Drying time per batch | Market price Per measure | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Fresh | Dried |

**APPENDIX B-1: TOMATO DRYING DATA OF FORCED CONVECTION SOLAR DRYER.**

| | AT | RH | RHDC | DC. T | | | Irrad. | WS | FIAS | FOAS | X | Y | OAS | MC $A_1$ | MC $A_2$ | MC $A_3$ | MC B | MC $C_1$ | MC $C_2$ | MC $C_3$ | MC D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8:00 am | 25 | 39 | 48 | 20 | 28 | 30 | 322 | 2 | 33 | 44 | 20 | 13 | 4 | 92.5 | 92.5 | 92.5 | 92.5 | 92.5 | 92.5 | 92.5 | 92.5 |
| 12:00pm | 43 | 28 | 23 | 32 | 46 | 50 | 846 | 2 | 33 | 45 | 20 | 12 | 3 | 70.1 | 74.2 | 80.6 | 85.4 | 68.6 | 74.1 | 75.8 | 80.5 |
| 3:00 pm | 40 | 33 | 21 | 34 | 42 | 48 | 855 | 2 | 35 | 40 | 18 | 10 | 4 | 54.2 | 58.6 | 68.5 | 76.3 | 41.5 | 53.5 | 56.3 | 67.2 |
| 6:00 pm | 36 | 37 | 25 | 32 | 38 | 40 | 230 | 4 | 35 | 59 | 22 | 8 | 6 | 42.6 | 49.0 | 60.4 | 68.6 | 18.6 | 33.4 | 37.9 | 58.5 |
| 8:00 am | 35 | 55 | 56 | 22 | 27 | 36 | 361 | 6 | 41 | 46 | 24 | 15 | 4 | 36.3 | 42.6 | 54.6 | 63.2 | 9.7 | 22.8 | 24.9 | 49.4 |
| 12:00pm | 45 | 35 | 29 | 34 | 42 | 46 | 804 | 4 | 35 | 40 | 22 | 10 | 5 | 27.9 | 33.7 | 45.7 | 56.6 | 7.2 | 11.8 | 12.4 | 43.4 |
| 3:00 pm | 44 | 31 | 20 | 36 | 43 | 48 | 636 | 6 | 33 | 52 | 20 | 10 | 4 | 20.3 | 25.4 | 38.3 | 52.3 | --- | 8.6 | 8.4 | 38.5 |
| 6:00 pm | 41 | 40 | 27 | 34 | 42 | 44 | 157 | 2 | 33 | 50 | 18 | 9 | 4 | 15.5 | 20.7 | 33.2 | 46.1 | --- | 7.3 | 7.2 | 33.2 |
| 8:00 am | 35 | 45 | 29 | 26 | 38 | 42 | 410 | 18 | 34 | 42 | 22 | 12 | 8 | 13.2 | 18.2 | 30.1 | 42.2 | --- | --- | --- | 29.2 |
| 12:00pm | 40 | 41 | 20 | 32 | 40 | 46 | 850 | 10 | 30 | 41 | 22 | 15 | 8 | 10.6 | 13.5 | 23.4 | 38.1 | --- | --- | --- | 24.2 |
| 3:00 pm | 42 | 19 | 16 | 34 | 38 | 44 | 860 | 10 | 32 | 44 | 25 | 19 | 10 | 9.2 | 8.2 | 17.3 | 34.7 | --- | --- | --- | 19.8 |
| 6:00 pm | 36 | 36 | 25 | 30 | 34 | 40 | 65 | 11 | 32 | 42 | 21 | 13 | 8 | 8.3 | 7.2 | 11.7 | 31.3 | --- | --- | --- | 15.6 |
| 8:00 am | 34 | 46 | 39 | 26 | 32 | 40 | 580 | 6 | 33 | 44 | 15 | 10 | 6 | 8.2 | --- | 8.3 | 30.4 | --- | --- | --- | 12.5 |
| 12:00pm | 44 | 44 | 50 | 30 | 42 | 46 | 768 | 6 | 33 | 46 | 20 | 14 | 8 | 7.6 | --- | 7.0 | 27.5 | --- | --- | --- | 9.6 |
| 3:00 pm | 40 | 22 | 25 | 36 | 40 | 44 | 519 | 2 | 30 | 47 | 22 | 11 | 6 | 7.4 | --- | --- | 25.4 | --- | --- | --- | 8.4 |
| 6:00 pm | 38 | 31 | 23 | 30 | 40 | 45 | 65 | 1 | 32 | 50 | 28 | 15 | 3 | 7.2 | --- | --- | 22.8 | --- | --- | --- | 7.2 |
| 8:00 am | 33 | 60 | --- | | | | 245 | 7 | | | | | | | | | 20.9 | | | | |
| 12:00pm | 46 | 49 | --- | | | | 788 | 4 | | | | | | | | | 18.7 | | | | |
| 3:00 pm | 40 | 33 | --- | | | | 376 | 2 | | | | | | | | | 16.5 | | | | |
| 6:00 pm | 36 | 46 | --- | | | | 49 | 2 | | | | | | | | | 14.6 | | | | |
| 8:00 am | 32 | 19 | --- | | | | 402 | 11 | | | | | | | | | 13.3 | | | | |
| 12:00pm | 44 | 29 | --- | | | | 632 | 2 | | | | | | | | | 12.5 | | | | |
| 3:00 pm | 40 | 32 | --- | | | | 456 | 2 | | | | | | | | | 11.3 | | | | |
| 6:00 pm | 36 | 50 | --- | | | | 248 | 2 | | | | | | | | | 10.2 | | | | |
| 8:00 am | 34 | 26 | --- | | | | 389 | 10 | | | | | | | | | 9.3 | | | | |
| 12:00pm | 46 | 23 | --- | | | | **725** | 4 | | | | | | | | | 8.5 | | | | |
| 3:00 pm | 45 | 28 | --- | | | | 502 | 2 | | | | | | | | | 7.8 | | | | |
| 6:00 pm | 36 | 41 | --- | | | | 86 | 2 | | | | | | | | | 7.5 | | | | |

**Drying Period: April 2nd 2003 to April 8th 2003**

AT = Ambient temperature ($^0$C)
RH =Relative humidity (%)
RHDC= Relative humidity in drying chamber (%)
Irrad = Irradiance (W/m$^2$)
W.S = Wind speed (km/hr)
FIAS = Fan intake air speed (km/hr)
FOAS = Fan output air speed (km/hr)
X = Air speed at 10m from inlet (km/hr)
Y = Air speed at 20m from inlet (km/hr)
OAS = Outlet air speed (km/hr)
DC.T = Drying chamber temperature at 1m, 10m, 20m from inlet ($^0$C)

MC $A_1$= Moisture content (%) wet basis of local sliced tomato at 1m from inlet
MC $A_2$= Moisture content (%) wet basis of local sliced tomato at 10m from inlet
MC $A_3$= Moisture content (%) wet basis of local sliced tomato at 22m from inlet
MC B = Moisture content (%) wet basis of local sliced tomato in open sun drying
MC $C_1$= Moisture content (%) wet basis of Eke's sliced tomato at 2.5m from inlet
MC $C_2$= Moisture content (%) wet basis of Eke's sliced tomato at 12m from inlet
MC $C_3$= Moisture content (%) wet basis of Eke's sliced tomato at 20m from inlet
MC D = Moisture content (%) wet basis of Eke's sliced tomato in open sun drying drying

**APPENDIX B-2 :TOMATO DRYING DATA OF NATURAL CONVECTION (CLOSED CHAMBER) SOLAR DRYER**

| DAY TIME | A.T | R.H | Irrad. | A.w.s | D.C T | M.C $A_1$ | M.C $A_2$ | M.C$A_3$ | M.C B | M.C $C_1$ | M.C $C_2$ | M.C$C_3$ | M.C D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8.00am | 34 | 26 | 389 | 10 | 40 | 92.5 | 92.5 | 92.5 | 92.5 | 92.5 | 92.5 | 92.5 | 92.5 |
| 12.00pm | 46 | 23 | 725 | 4 | 49 | 86.6 | 87.7 | 86.2 | 87.5 | 77.4 | 79.5 | 78.4 | 80.8 |
| 3.00pm | 45 | 28 | 502 | 2 | 49 | 78.3 | 79.4 | 80.3 | 81.2 | 60.3 | 68.6 | 65.6 | 71.3 |
| 6.00pm | 36 | 41 | 103 | 2 | 45 | 72.9 | 74.3 | 75.6 | 75.4 | 48.5 | 62.4 | 55.6 | 64.8 |
| 8.00am | 33 | 49 | 368 | 13 | 35 | 68.9 | 70.5 | 71.4 | 73.8 | 39.6 | 59.2 | 48.3 | 60.3 |
| 12.00pm | 48 | 31 | 768 | 6 | 50 | 62.2 | 62.9 | 66.3 | 66.8 | 28.3 | 50.5 | 39.7 | 54.4 |
| 3.00pm | 45 | 25 | 519 | 2 | 50 | 56.4 | 54.8 | 60.6 | 61.2 | 19.8 | 40.1 | 31.4 | 49.3 |
| 6.00pm | 38 | 30 | 65 | 1 | 48 | 49.7 | 49.5 | 57.3 | 56.3 | 12.5 | 32.9 | 25.8 | 46.6 |
| 8.00am | 32 | 45 | 326 | 8 | 34 | 45.8 | 46.3 | 52.6 | 54.0 | 9.4 | 30.8 | 19.4 | 40.7 |
| 12.00pm | 46 | 29 | 776 | 5 | 52 | 40.0 | 41.1 | 48.3 | 49.6 | 8.3 | 25.6 | 12.7 | 36.4 |
| 3.00pm | 42 | 25 | 482 | 3 | 48 | 33.9 | 36.8 | 44.4 | 45.9 | 7.6 | 18.4 | 9.6 | 32.3 |
| 6.00pm | 36 | 51 | 60 | 2 | 40 | 27.7 | 33.4 | 41.2 | 42.7 | 7.2 | 11.4 | 7.4 | 28.9 |
| 8.00am | 33 | 54 | 245 | 7 | 38 | 22.2 | 28.9 | 37.3 | 38.4 |  | 9.6 |  | 25.8 |
| 12.00pm | 46 | 36 | 788 | 4 | 51 | 16.6 | 25.4 | 33.6 | 35.2 |  | 8.3 |  | 20.4 |
| 3.00pm | 42 | 29 | 376 | 2 | 50 | 12.2 | 20.2 | 29.6 | 32.1 |  | 7.4 |  | 16.8 |
| 6.00pm | 36 | 53 | 49 | 1 | 46 | 11.3 | 17.3 | 25.7 | 28.6 |  |  |  | 14.8 |
| 8.00am | 34 | 51 | 324 | 10 | 38 | 10.5 | 15.6 | 22.3 | 25.3 |  |  |  | 12.7 |
| 12.00pm | 44 | 38 | 822 | 6 | 52 | 9.6 | 14.3 | 19.4 | 22.6 |  |  |  | 10.1 |
| 3.00pm | 40 | 30 | 420 | 2 | 45 | 8.3 | 12.6 | 17.3 | 18.2 |  |  |  | 8.7 |
| 6.00pm | 34 | 49 | 50 | 2 | 38 | 7.5 | 10.6 | 15.6 | 16.3 |  |  |  | 7.2 |
| 8.00am | 34 | 48 | 416 | 13 | 40 |  | 9.4 | 13.3 | 14.5 |  |  |  |  |
| 12.00pm | 45 | 38 | 886 | 4 | 49 |  | 8.4 | 10.8 | 13.3 |  |  |  |  |
| 3.00pm | 44 | 38 | 667 | 4 | 50 |  | 7.3 | 8.8 | 11.8 |  |  |  |  |
| 6.00pm | 40 | 49 | 56 | 2 | 48 |  |  | 7.4 | 10.5 |  |  |  |  |
| 8.00am | 32 | 48 | 420 | 11 | 38 |  |  |  | 9.4 |  |  |  |  |
| 12.00pm | 44 | 50 | 835 | 9 | 50 |  |  |  | 8.6 |  |  |  |  |
| 3.00pm | 42 | 53 | 553 | 10 | 48 |  |  |  | 7.7 |  |  |  |  |
| 6.00pm | 36 | 41 | 72 | 4 | 40 |  |  |  | 7.3 |  |  |  |  |

**Drying Period: April 7th 2003 to April 13th 2003**

A.T = Ambient temperature ($^0$C)
R.H = Relative humidity (%)
Irrad = Irradiance (W/m$^2$)
Aws = Ambient wind speed (km/hr)
D.C T = Mean drying chamber temperature ($^0$C)
M.C $A_1$ = Moisture content (%) wet basis of local sliced tomato 1m away from inlet
M.C $A_2$ = Moisture content (%) wet basis of local sliced tomato 14m away from inlet
M.C $A_3$ = Moisture content (%) wet basis of local sliced tomato 27m away from inlet.
M.C B = Moisture content (%) wet basis of local sliced tomato in open sun drying
M.C $C_1$ = Moisture content (%) wet basis of Eke's sliced tomato 3m away from inlet
M .C $C_2$ = Moisture content (%) wet basis of Eke's sliced tomato 16m away from inlet
M.C $C_3$ = Moisture content (%) wet basis of Eke's sliced tomato 29m away from inlet.
M.C D = Moisture content (%) wet basis of Eke's sliced tomato in open sun dying

**APPENDIX B-3: NATURAL CONVECTION (OPEN CHAMBER) SOLAR DRYER**

| DAY TIME | A.t. | R.H | Irrad. | A.w.s | M.C A | M.C B | M.C C | M.C D |
|---|---|---|---|---|---|---|---|---|
| 8.00am | 32 | 48 | 420 | 11 | 92.5 | 92.5 | 92.5 | 92.5 |
| 12.00pm | 44 | 50 | 835 | 9 | 88.2 | 87.4 | 82.6 | 82.9 |
| 3.00pm | 42 | 53 | 553 | 10 | 80.4 | 82.6 | 72.1 | 73.6 |
| 6.00pm | 36 | 41 | 72 | 4 | 77.1 | 78.2 | 65.4 | 64.5 |
| 8.00am | 30 | 39 | 320 | 10 | 75.3 | 76.2 | 58.9 | 56.8 |
| 12.00pm | 46 | 27 | 836 | 6 | 68.9 | 70.9 | 49.3 | 48.6 |
| 3.00pm | 42 | 23 | 548 | 6 | 61.8 | 65.6 | 40.4 | 42.3 |
| 6.00pm | 36 | 30 | 55 | 2 | 56.5 | 63.2 | 36.3 | 35.4 |
| 8.00am | 34 | 34 | 350 | 11 | 54.5 | 58.1 | 29.6 | 28.0 |
| 12.00pm | 48 | 23 | 773 | 8 | 48.5 | 53.8 | 25.9 | 20.2 |
| 3.00pm | 40 | 18 | 602 | 4 | 45.8 | 48.3 | 18.8 | 16.6 |
| 6.00pm | 37 | 22 | 95 | 4 | 40.3 | 43.6 | 14.5 | 13.2 |
| 8.00am | 32 | 43 | 302 | 9 | 36.3 | 40.8 | 10.4 | 11.3 |
| 12.00pm | 44 | 27 | 802 | 4 | 32.5 | 35.2 | 9.3 | 9.5 |
| 3.00pm | 38 | 34 | 531 | 4 | 28.6 | 29.7 | 7.5 | 8.6 |
| 6.00pm | 34 | 44 | 85 | 6 | 25.4 | 25.7 |  | 7.4 |
| 8.00am | 34 | 49 | 356 | 8 | 20.6 | 20.6 |  |  |
| 12.00pm | 48 | 18 | 812 | 4 | 16.7 | 18.5 |  |  |
| 3.00pm | 42 | 23 | 513 | 2 | 13.9 | 16.7 |  |  |
| 6.00pm | 32 | 26 | 70 | 2 | 11.2 | 14.7 |  |  |
| 8.00am | 32 | 42 | 382 | 8 | 9.3 | 13.8 |  |  |
| 12.00pm | 42 | 30 | 776 | 4 | 8.7 | 11.6 |  |  |
| 3.00pm | 38 | 34 | 450 | 4 | 7.8 | 10.3 |  |  |
| 6.00pm | 32 | 26 | 90 | 6 | 7.2 | 9.6 |  |  |
| 8.00am | 32 | 48 | 420 | 6 |  | 8.9 |  |  |
| 12.00pm | 44 | 38 | 835 | 4 |  | 8.0 |  |  |
| 3.00pm | 42 | 28 | 553 | 4 |  | 7.6 |  |  |
| 6.00pm | 32 | 41 | 72 | 7 |  | 7.3 |  |  |

**Drying Period: April 13th 2003 to April 19th 2003**

A.t = Ambient temperature ($^0$C)
R.H = Relative humidity (%)
Irrad = Irradiance (W/m$^2$)
A.w.s = Ambient wind speed (km/hr)
M.C A = Moisture content (%) wet basis of local sliced tomato in open drying chamber
M.C B = Moisture content (%) wet basis of local sliced tomato in open sun dryer
M.C C = Moisture content (%) wet basis of Eke's sliced tomato in open drying chamber
M.C D = Moisture content (%) wet basis of Eke's sliced tomato in open sun dryer

# APPENDIX C

## CONSTRUCTION MATERIALS COST ESTIMATES.

| MATERIALS | SIZE | QTY. | COST (₦) |
|---|---|---|---|
| 1. Mud Block | 30cm x 20cm x 10cm | 900 | 4500 |
| 2. Asabari | 200cm x 100cm | 20 | 2000 |
| 3. Black Afara(wood) | 0.05m x0.305 x 4m | 20 | 3000 |
| 4. Batten | 2" x ¼" x 2' | 80 | 3200 |
| 5. Polythene | 15 yds | 15 yds | 1200 |
| 6. Sand | - | 4 tippers | 6600 |
| 7. Nails | | | 350 |
| 8. Blower | | | 10000 |
| 9. Diesel Engine | 5.9hp (4.4 KW) | 1 | 30000 |
| **TOTAL** | | | **₦ 60,850** |

## APPENDIX D

## Nutrient Composition of Tomato (per 100g)

| | Energy(Kcal) | Water(g) | Carbohydrate(g) | Vitamin C (mg) | Thiamine (mg) | Riboflavin (mg) | Niacin (mg) | Vitamin A (IU) | Fat (g) | Protein (g) |
|---|---|---|---|---|---|---|---|---|---|---|
| Tomato juice, canned | 17 | 93.90 | 4.23 | 18.3 | 0.047 | 0.031 | 0.673 | 556 | 0.06 | 0.76 |
| Tomato, red, ripe | 21 | 93.76 | 4.64 | 19.1 | 0.059 | 0.048 | 0.628 | 628 | 0.33 | 0.85 |
| Tomato, sun-dried | 258 | 14.56 | 55.76 | 39.2 | 0.528 | 0.489 | 9.050 | 874 | 2.97 | 14.11 |

Sources : US Department of Agriculture 2004.

**APPENDIX E**

**MOISTURE CONTENT (OVEN DRY METHOD) OF FRESH TOMATO**

| Weight of fresh tomato (g) | Weight of oven dried tomato (g) | Weight of water removed (g) | Moisture content wet basis (%) |
|---|---|---|---|
| 112.2 | 7.29 | 104.91 | 93.5 |
| 120.21 | 9.71 | 110.50 | 92.0 |
| 125.6 | 9.96 | 115.64 | 92.1 |

Average moisture content wet basis = $\frac{93.5+92.0+92.1}{3}$ = 92.5%