DESIGN, CONSTRUCTION AND CHARACTERISATION OF CABINET SOLAR DRYER WITH STORAGE FACILITY

BY

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CERTIFICATION

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DEDICATION

This work is dedicated to the glory of Almighty God, who is the source of all strength, blessing and protection

ACKNOWLEDGEMENT

First and foremost, I am grateful to God for his grace and strength throughout the period of this research.

Also I am very much indebted to my project supervisor, Dr. A. Babatunde Rabiu for his careful supervision of this work in form of reading, creative criticism, correction and valuable suggestions and encouragement. Appreciation also goes to all the staff of Physics Department, Federal University of Technology, Akure, especially Prof. (Mrs.) I.A. Fuwape, (Head of Department), Dr. O.S. Ajayi, Dr. M.O. Ajewole and Dr. M.T. Babalola.

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ABSTRACT

A passive solar cabinet dryer with dimensions (0.909 m X 0.602 m X 0.601 m) was constructed using wood as the frame for the outside cover, while the inside was lined with foam as an insulator and Aluminum plate painted black was used as the receiver. A flat plate collector which was a double layered glass served as the uppermost covering. Solar thermal storage device was integrated with the dryer. The performance of the solar dryer was evaluated using plantain chips, pepper and fish. The drying inside the dryer was compared to drying in the open air. The drying process was done in six days. The amount of energy trapped or absorbed by the dryer was computed. Also, throughout the period under study, the temperature in the dryer was found to be higher than the ambient temperature. This gave the dryer a lot of advantage over the open air drying.

CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND OF THE STUDY

One of the oldest uses of solar energy since the dawn of civilization has been the drying and preservation of agricultural products. The method used is simple and often crude but reasonably effective. Basically, crops are spread on the ground or platforms often with no pretreatment and are turned regularly until they are sufficiently dried so that they can be stored for later consumption.

However, drying in the open sun like this is not hygienic. It always take long time to dry and rain may slow down the drying process. Due to time constraints, the food is not always fully dried, sometimes resulting in re-growth of bacteria and fungus. Also dust and atmospheric pollution with intrusion from insect infestation, animal and man are problems to this traditional method of drying.

Therefore, artificial drying using solar energy has in many cases supplement traditional sun drying in order to achieve better quality control, reduce spoilage, hygienic food and in general cut down the losses and ineffeciencies mention above.

Also, relative high cost of labour in most industralized areas and high costs of fossil fuels necessitated the development of the solar dryer for drying processes.

1.1 SOLAR DRYER

The solar dryer is an equipment which utilizes sunlight as its fuel. It consist of box which is lined with aluminium plate and covered with glass. The glass acts as the transmitter for the sunlight energy while the aluminium plate serve as the absorber. Other materials that can be used as absorbers include copper and steel sheet.

Glass is a material that have high transmittance for electromagnetic waves with short wavelength. Sunlight is an example of such wave. Also, glass is opaque to long wave in the electromagnetic spectrum in which heat belongs to. Therefore, when sunlight falls on the glass, it is tranmitted to the absorber which is converted to heat. The generated heat is trapped down by the glass to be used by the dryer for the drying of the material.

With these it is obvious that any material or food stuffs inside the dryer would dry faster than when placed directly inside the open sun.

The dryer has a lower inlet through which fresh air enters it and an upper outlet through which damp air escapes.

Moreover, the project-type has an auxiliary facility that provided additional heat to the dryer and also a thermal storage facility that can provide heat energy in the night when there is no solar radiation. All these enhance effectiveness of the dryer

The following are some advantages of a solar dryer for drying processes:

(1) It dries food much faster than drying in the open space
(2) It protects the food from dust, insects, flies, birds and animals.
(3) It saves time since less attention has to be given to the materials to be dried.
(4) Better quality and nutritious dry food are produced with the use of solar dryer.
(5) It is very simple and of low-cost technology
(6) It can be easily turned towards the sun for effective drying
(7) It can be used for small dried food business

1.2 AIMS AND PURPOSE OF STUDY

Many devices have been designed and invented for the conversion of solar energy into useful forms for direct use by man. This has made life more pleasant, lively and comfortable for man. Examples of such include solar heating and cooling, electricity generation, solar powered space vehicles and satellites, telecommunications e.t.c.

However, this project is concentrating on space heating for the purpose of drying agricultural products in Nigeria. A cabinet solar dryer with solar thermal energy storage system will be constructed. Its performance would be compared with open air drying and cooking.

With these, the country can engage in a more advantageous agricultural practice because for a country to be able to feed her citizens very well, she must have a good production, processing and storage system to prevent food wastage. The use of solar dryer can guarantee this. It would ensure that agricultural products dry faster and more hygienic, compared to unsatisfactory old method of drying food items in the open sun. Also the food items might go bad due to slow drying process or be eaten up by rodents and other animals, however with the use of solar dryer all this awkward conditions are overcome.

Also solar dryer can be used for a small scale business either by producing and selling it or using it to dry food materials faster for sales.

Furthermore, with the prices of petroleum products and gas increasing daily with electricity as well, solar dryer can be used to cook when the sun intensity is high enough.

CHAPTER TWO

LITERATURE REVIEW

2.0 SOLAR ENERGY

This is the energy that is received on the earth from the sun. It reaches the earth through radiation from space as a result of the nuclear fussion reaction going on in the core of sun.

2.1 NATURE OF THE SUN

Sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9 m,at a distance of about 1.5×10^{11} m from the earth. It rotates on its axis about once every four week. However, it does not rotate as a solid body, the equator takes about twenty Seven days and the polar regions take about 30 days for each rotation.

It has effective black body temperature of 5762 K. The temperature of the innermost region, the core is estimated to be between 8×10^6 and 40×10^6K and the density about 100 times that of water.

The sun is a continuous fussion reactor with its constituent gases as the containing vessel retained by gravitational forces. The gravitational forces prevent the reaction (plasma reaction) from touching the wall of the container or else the reaction would stop due to cooling for several seconds. Various fussion reaction have been suggested to be going on in the sun. But the most important is the process in which four hydrogen atoms combine to form one helium atom. The mass of the helium atom is lesser than the four hydrogen atoms. This loss in mass during the reaction is converted to energy.

This energy is produced in the interior of the solar sphere at temperature of many millions degrees. It is therefore transferred to the surface and radiated into space through succession of radiative and convective processes. The sun's core is in the x-ray and gamma ray parts of the spectrum with the wavelengths of the radiation increasing as the temperature drops at larger radial distances.

A schematic representation of the structure of the sun is shown in Fig. 1.0 It is estimated that 90% of the energy is generated in the region of 0-0.02 R (where R is the radius of the sun) which contains 40% of the mass of the sun. At a distance of 0.7 R from the center, the temperature drops to about 130,000 K and the density to 70 km/m^3. Convection begins to be more significant at this region.

Convection is significant from 0.7 to 1.0 R. This region is known as convective zone. Within this zone the temperature drops to about 500 K and the density to about 10^{-5} kg/m^3

Other features of the solar surface are small dark areas called pores, which are of the same order of magnitude as the convective cells, and larger dark area called sunspots which vary in size. The outer layer of the conventive zone is called the Photosphere. It is the source of the most of the solar radiation. Above the photosphere is a layer of cooler gases several hundred kilometres deep called the reversing layer. Following the reversing layer is the chromosphere having a depth of about 10,000km. It is a gaseous layer with temperature somewhat higher than that of the photosphere and with lower density. The corona of the very low density and very high temperature (10^6 K) is the outer layer.

With these, the physical structure, temperature and density gradients of the sun enable one to appreciate the sun. It is not only functioning as a black body radiating heat at fixed temperature but rather the emitted solar radiation is the composite result of several layers that emit and absorb radiation of various wavelengths.

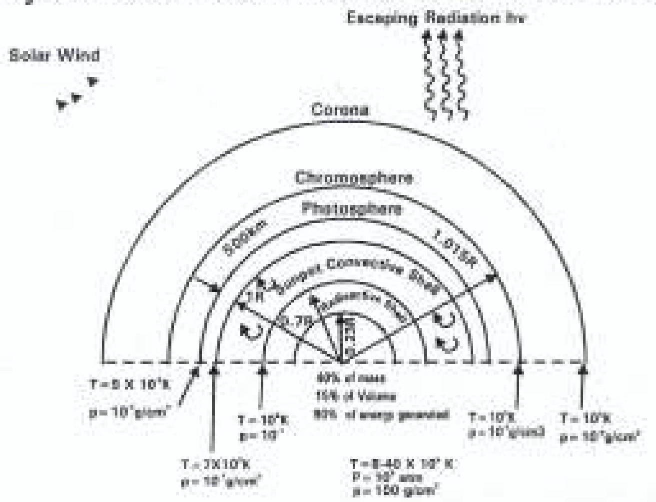


Fig. 1.0 The structure of the Sun

2.1.1 SOLAR CONSTANT

The solar constant is the energy from the sun per unit time, received on a unit area of surface perpendicular to the direction of propagation of the radiation at the earth's mean distance from the sun outside the atmosphere.

Until recently, estimates of the solar constant had to be made from the ground-based measurements of solar radiation after it had been transmitted through the atmosphere and this in part, absorbed and scattered by components of the atmosphere. Extrapolations from the terrestrial measurements which were made from high mountains, were based on estimates of atmospheric transmission in various portions of the solar spectrum.(Duffie and Beckman, 1980)

C.G Abbot and his colleagues at the Smithschia institution gave a value of 1322W/m^2. This was later revised through rockets measurement by Johnson to 1395 W/m^2.

Recently with the availability of very high altitude aircraft, ballons and space craft, direct measurements were made with a variety of instruments in nine separate experimental programs. These resulted in a value of 1353 W/m^2. However, the World Radiation Centre (WRC) has adopted a value of 1367 W/m^2 (1.960 Cal/cm^2 min, 432 Btu/Ft^2 hr or 4.92 MJ/m^2h) with and uncertainty of the order of 1%. This is the most accepted value of the solar constant, (Garg and prakash, 1997)

2.1.2 DEPLETION OF SOLAR RADIATION BY THE ATMOSPHERE

It has been observed that the solar radiation obtained on the earth is lesser than that obtained outside the earth. This is due to absorption. The atmosphere contains various gaseous constituents, suspended dust and other minute solid and liquid particulate matter and clouds of various types.

Therefore, the solar radiation is depleted during its passage through the atmosphere before reaching the earth's surface. If the atmosphere is very clear then the depletion in the solar radiation occurs simultaneously by three distinct physical processes. They are:-

(1) Selective absorption:- Absorption by water vapour, molecular oxygen, ozone and carbondioxide in certain wavelengths.

(2) Rayleigh Scattering:- By molecules of different gases and dust particles that constitute the atmosphere.

(3) Mie Scattering:- Scattering by air molecules of gaseous particles where their size is very small compared to the wavelengths of radiation (λ^{-4} to λ which is the wavelength of radiation)

With these, three types of radiation reached the earth. They are:-

(1) Direct Radiation:- This is the radiation from the sun that reaches the earth without any absorption by any atmospheric matter.

(2) Diffuse Radiation:- Radiation that is received from the sun after depletion and absorption of the solar radiation in the atmosphere. Roughly one half of the scattered radiation is lost to space and the remaining half is directed downwards to the earth's surface from different directions. (Garg and Prakash, 1997).

(3) Global Radiation:- The combination of direct radiation and diffuse radiation form the global radiation.

It should be noted that the fraction of the total solar radiant energy reflected back to the space by reflection from the clouds, scattering by the atmospheric gases and dust particles and by reflection at the earth's surface is called the albedo of the earth atmosphere system and has a value of about 0.30 for the earth as a whole (Garg and Prakash, 1997).

Thus, on the surface of the earth we receive the direct radiation which reaches the earth's surface unchanged in direction and wavelength, and diffuse radiation, the direction of which is changed by scattering and reflection. The addition of the two constitute the global radiation.

2.1.3 INSTRUMENTS FOR MEASURING SOLAR RADIATION

The instruments generally used for measuring different radiation parameters are:

(1) Pyrheliometer :- For measuring the intensity of direct solar radiation at normal incidence.

(2) Pyregenometer :- For measuring the net flux of long-wave radiation through a horizontal surface during the night.

(3) Pyranometer :- For measuring the global solar radiation received from the entire hemisphere. When fitted with a shading ring it measures the diffuse radiation, and when mounted with its sensor facing downwards it measures reflected solar radiation, and which when expressed as a fraction of global radiation gives the albedo. (Hewith et al, 1994)

(4) Net Pyradiometer :- For measuring the net flux of downward and upward total radiation (short-wave and long-wave radiation) through a horizontal surface.

2.1.4 USEFULNESS OF SOLAR ENERGY

The usefulness of Solar energy starts from photosynthesis; the process by which plants manufacture its food. Carbondioxide and water are converted to sugar in the presence of a pigment called Chlorophyll. This vegetation rots away and the ever great pressures and temperatures exerted upon this composted, recycled material during the passage of thousands upon thousand of years processes this gradually into the solid, liquid and gaseous fuels (various petroleum products) that warm our homes, heat our food, propel our transport and progress the march of industrial sophistication.

Solar energy is also used by man to dry food stuff, hides and skin, It is used for distillation, salt production by evaporating salt laden water.

Solar energy is also used for electricity generation, power for space satilites and telecommunication materials.

The importance and usefulness of solar energy cannot be overemphasised, It is believed that, if properly harnessed, it would be one of the major sources of the world electric and power supply.

2.1.5 LIMITATION OF SOLAR ENERGY

Despite its wide applications, solar energy still has some limitations. Its limitation include:

(1) Absence of Solar radiation in the night always create an intermittent or power-break from materials using solar energy as their major source of power supply. Except a back-up is provided, this always create a major set back or nuisance.

(2) Even in the afternoon when there should be an enormous radiation, what we receive on earth is always a minute of what is produced in the sun. This is due to absorption and scattering of solar radiation in the atmosphere by the atmospheric particles.

(3) Nearly all the appliances using solar energy cannot convert all the solar radiation incident on them to useful power. There is always incomplete absorption and use of solar radiation during excessive radiation unless a storage is provided.

2.2 SOLAR COLLECTOR

This is a device used in energy conversion system to convert solar radiation into heat for cooling and heating purposes. The collector is usually made up of two components; the glaze which is usually a glass (at times plastic) and the absorber. These absorbers are the materials that absorb the solar radiation and convert it to heat. The glaze on the other hand traps the heat radiated by the absorber or else the absorber will virtually lose all the heat to the surrounding.

Another important property of glaze is the ability to transmit sunlight in the short wave band and trapping of heat wave in the long wave band. There are various types of solar collectors, these include: Flat plates collectors, Concentrating collectors, Vacuum tube collectors. Some collectors have single glaze while some have two or multiple depending on the type that one needs.

2.2.1 FLAT PLATE COLLECTOR

This is made up of a glass cover and a flat conducting absorber sheet which is insulated to prevent heat loss. Copper is the preferred material for its high conductivity and in the case of liquid for its resistance to corrosion but it is expensive. Aluminium offers fairly high conductivity but it is cheaper than copper and it is susceptible to corrosion.

Flat plate collectors heat transporting fluid whether air or liquid, it flows through the tubes that are bonded to the absorber sheet. Since the tubes are some distances apart, good conductivity of the absorber sheet is important.

2.2.2 FOCUSSING OR CONCENTRATING COLLECTORS

These are curved or parabolic reflectors used to concentrate the solar radiation to a focus. The absorber material is located at the point of focus of the radiation. This reflector could be highly polished metal reflector or plane mirror. Due to its ability to generate high temperature that can produce high grade energy it is used for heating and air conditioning system.

2.2.3 TRACKING CONCENTRATORS

These are collectors that are used to track the sun. However, collectors that have high concentration ratio should be used.

The collectors that most suitable for tracking includes parabolic reflectors, fresnel lenses e.t.c. It should be noted that the receiver must have a minimum size if it is to intercept most of the incident radiation. The choice of the optimal absorber size involves a compromise between optical and thermal performance. If the absorber is too large most of the incident solar radiation will be intercepted but the heat losses are excessive. On the other hand a very small absorber has low heat loss but it will also miss too much of the available solar radiation (Rabi, 1985).

2.2.4 PARABOLIC REFLECTORS

This type of reflector can be built either as a trough or as a dish. It is one of the best known solar concentrators. It can take variety of shapes either flat or round.

The parabola is made to track the sun so that at any point in time the rays of the sun striking the dish will be parallel to the optical axis of the parabola. With these perfect focusing is possible only for rays that are incident parallel to the optical axis of the parabola. A collimated beam coming from other directions will not only miss the focus but due to off axis aberrations of the parabola, will not even converge into a single point.

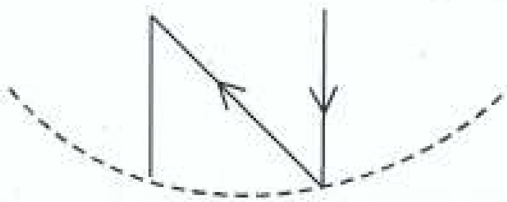
Therefore, if the absorber is to intercept all rays, it must be made sufficiently large and placed at the focal line. This type of design and arrangement has given temperature range of 150-3000°C

2.2.5 FRESNEL REFLECTORS

Fresnel reflectors is made up of reflectors or lens broken into segment to track the sun. The use of smooth optical surface or parabolic reflector becomes uneconomical in practice as the area of the reflector increases beyond 100 m^2. Also mechanical problems of weighing and intense wind jointly constitutes a disadvantage.

Therefore, Fresnel reflectors invented by Fresnel is good for large installations. It consists of a field heliostat of several mirrors that track the sun. The energy reflected by these individual mirrors is collected by a centre receiver located on top of a tower in the centre of the field.

The tracking character of Fresnel reflectors is shown in Figs. l.la and l.lb



(a) Tracking the sun when it is overhead

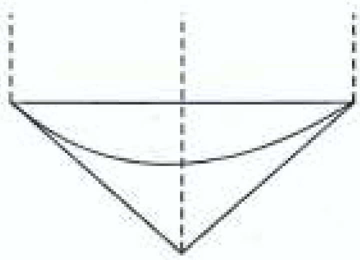
(b) Tracking the sun when its incidence angle is θ

Figs.l.l Tracking character of Fresnel reflectors

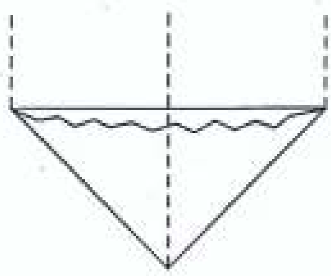
2.2.6 FRESNEL LENS

The use of ordinary lens is impracticable in most solar applications because the lens would have to be very thick, mass per aperture should be proportional to the aperture width, widths are larger than few centimetres. This offer a very inconvenient as the mass and weight becomes excessive.

Fresnel lens offers a very good alternative. It is used as refractive concentrator that track the sun especially for voltaic solar cell.



(a) A Reflective Concentrator using ordinary lens



(b) A Reflective Concentrator using a Fresnel lens

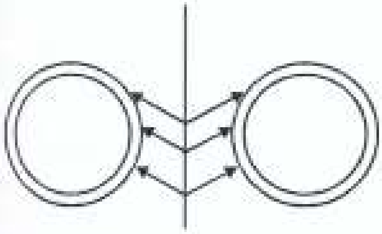
Fig.1.2 Reflective Concentrators

2.2.7 EVACUATED OR VACCUM TUBE COLLECTOR

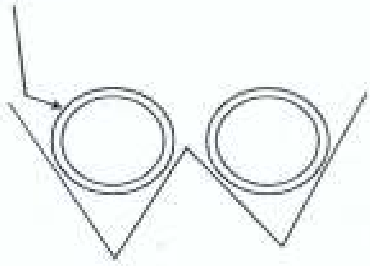
The collector consists of an array of clear cylindrical tubes similar to those used in flourescent lamps. The tubes are fastened side by side to form a rectangular panel. They admit more light than flat plate. Therefore, the collector is used when higher temperature and high efficiency is required.

This design reduced collector heat losses because of the vaccum. The transparent tubes are arranged in parallels to form a reflector plate. Within each tube are usually one or more absorbed tubes.

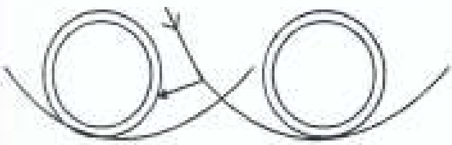
The plastic foams that formed the body offers a very high temperature and the reflectors used for this type of design include diffused reflector, V-groove reflector, Circular reflector and Compound parabolic concentrator.



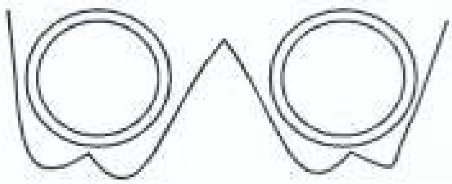
(a) Diffused Reflector



(b) V- Groove Reflector



(c) Circular Reflector



(d) Compound Parabolic Reflector

Fig.1.4

2.2.8 FIXED REFLECTORS WITH TRACKING RECEIVER

The design is made up of a large reflector that is fixed and a small receiver that track the sun. There are about three such systems that are known. They are Circular cylindrical reflector with tracking receiver, Hemispherical reflector and reflector slates on circular cylindrical mount.

A solar air heater system consist of an array of interconnected solar heat collectors. Most systems incorporated a once - through or single-pass type of forced air circulation with cold ambient air intake and solar heated air discharge to the working place. The collectors may be connected in series, parallel or series-parallel combination. A series-only connection would result in a long but higher temperature system whereas a parallel only connection will result in a short but lower temperature system. (Ong, 1995).

Basically, there are two different types of air collectors with several different design features each. These are air collectors of a conventional design with an absorber plate being over or underflown by the working fluid and matrix air. The other is the collectors with the working fluid flowing throught the absorber matrix. (Kolb et al, 1999).

It should be noted that for a good collector system, the reflecting surface must have high quality and good specular reflectance properties. Due considerations must be given to the effect of accumulation of dust and contamination, stability of the reflective coating environmental effects, cleaning problems and cost.

Also the factors on which the choice of absorber receiver materials depends are:

(1) Physical properties such as melting point, thermal strength modulus of elastic ity and yield strength.
(2) Cost of materials
(3) Ease of fabrication
(4) Corrosion resistance of the outer and inner surfaces to surroundings and heat transfer fluid respectively.
(5) Resistance to stagnation temperature conditions
(6) Energy effectiveness in use of material, for example, energy consumed to pro duce steel has been estimated to be 16500 kJ/ kg, for Aluminium 144,000 kJ/kg and for copper 93,000 kJ/kg. Precisely, durable, strong and energy economic absorber materials must be used. (Garg and Prakash, 1997).

Materials like Copper, Steel and Aluminium offer a very good properties.

For the heat transfer fluids for a collector whether flat plate or concentrators, the following properties must be ensured:

(1) High operating temperature
(2) Stability at high temperature
(3) Low material maintenance and transport costs
(4) Non-corrosive
(5) Safe to use
(6) Low vapours pressure

2.3 THE NEED FOR THERMAL ENERGY STORAGE

Thermal energy storage is very important and useful in any energy conversion system. It reduces the time or rate mismatch between energy supply and energy demand thereby playing a vital role in energy conservation. It improves the performance of energy systems by smoothening the output and thus increasing reliability, some of the renewable energy systems e.g. solar energy can provide only and intermittent energy supply therefore a back-up or auxiliary energy source becomes essential.

Therefore, provision of thermal energy storage in the device (solar energy dryer) can reduce rate mismatch between the supply and demand of solar energy, and also smoothening the output and make the dryer reliable. Moreover, it reduces auxiliary energy consumption to a great extent and increases the so called solar load fraction substantially thus conserving the valuable fossil fuel reserves, coal, oil and natural gas. With this the dryer can perform its function of drying both in the day and in the night and reduce the total cost.

2.3.1 SIZE AND DURATION OF STORAGE

The type and extent of rate mismatch varies from system to system influencing the type and size of storage. For instance the following factors have to be taken into consideration.

(i) A case where the energy supply from the source is constant but there is variation in the load. Therefore, a good storage is needed to store excess heat when the load consumption is small. The stored heat is later used when the load consumption is high, with these the system can be working all the time.

(ii) When the energy supply is variable but the load is constant. Therefore, a stor age is needed to store excess heat to be used when needed

(iii) Another case is when both the supply and demand is varying. Storage is also needed to store excess heat when it is not needed to be used when needed.

(iv) Another extreme case is where solar energy is available only in one season (Winter). Therefore, excess heat during summer goes into reserve for use during winter. This type of storage is called long term storage.

Also, the size of storage should also be considered. Smaller storage provides large energy density with lesser quality of storage material and small size of the compartment. This device has advantages in both habitat and transport applications than larger storage devices with little energy density.

The duration that the stored heat can go is also a parameter. For example if energy is converted into fuel such as hydrogen, it can be stored almost indefinitely. However, if energy is stored as thermal energy one has to ensure that the thermal losses during the length of time for which the energy is to be stored are within acceptable limits.

In case of solar dryer, the short term storage means storing the day-night period or sometimes for a few days is used.

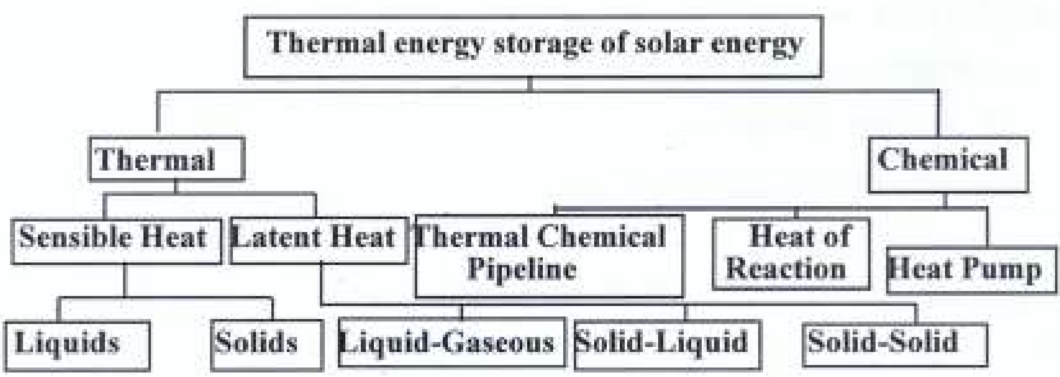
Short term storage is a dynamic system that undergoes a daily Charge/discharge cycle and therefore plays significant role in the performance of solar heating system.

2.3.2 TYPES OF ENERGY STORAGE

Thermal energy can be stored in well insulated fluids or solids. It is generally stored as either:

(i) Sensible heat:- By the virtue of the heat capacity of the storage medium.

(ii) Latent heat:- By the virtue of the latent heat. (iii) By utilising both sensible heat and latent heat together.



2.3.3 SENSIBLE HEAT STORAGE

It involves the use of heat capacity of the storage medium, the following can be employ to effect it:

(a) Storage in water which involves the storing of hot water in well insulated tanks. Only for a few days since the heat losses become prohibitive over long durations. Example of this is the electric geyer and the domestic solar water heater. However, this method is only good for smaller temperature range and it is of low cost and large heat capacity. Also, it can also act as the heat transfer fluid to and from the storage.

(b) Solar ponds in which the ponds act as the solar collector and the storage. Solar radiation is absorbed in the water and rest in the black layer (a water-impervious black inner).

The water itself is used as an insulator, therefore a depth of about 1m is required. Convection is suppressed by maintaining a density gradient from bottom to top by providing a salt concentration gradient in the same direction. Corresponding to four methods of convection suppression, four types of solar ponds are identified:

(i) Salt gradient (ii) Gel or Viscosity stabilize

(iii) Saturated (iv) Naturally existing saline solar ponds

(c) Storage in other liquids whose thermophysical properties suit the desired temperature range. Examples of such liquid include Ethanol, Engine Oil, Butanol e.t.c.

(d) Storage in solids that have good thermophysical properties. Energy is stored at low or high temperature since these will not freeze or boil. Solid materials that can be used for this purpose inicude rocks, metals, concrete, sand bricks, e.t.c. When a gap exist between availability and requirement of energy, temporary storage of energy is needed to maintain the continuity of the thermal process. Rock bed energy storage is generally preferred for the air based thermal energy storage system. (Choudhury et al, 1995)

(e) Storage in dual media. This involves the use of both solid and liquid together. Example is the use of water tank whose container is a earth wall and filled with earth, rocks or sand. The addition of solids into the liquid facilitates temperature stratification in the storage vessel. A dual media unit is being considered for applications in commercial power plants or 100 MW electric and larger capacity.

2.3.4 LATENT HEAT STORAGE

Since it involves the use of phase change in a material, the following methods can be applied

(a) Salt hydrates that have water of crystallisation can be used. The only problem here is the incogruent melting caused by the fact that the released water of crystallization is not sufficient to dissolve all the solid phase present. This recrystallisation can be done either by the use of suspension media or thickening agents or by mechanical means.

(b) The use of paraffins, due to their availability in a large temperature range and their reasonably high heat of fussion. They are known to freeze without super cooling. With these they can be used for heat storage.

(c) Non-paraffins can also be used for heat storage because of their high heat of fussion, inflammability e.t.c. They undergo slow reproducible melting and freezing behaviour and freeze with almost no super cooling.

(d) Inorganic compounds and eutectic can also be used for heat storage. Example of such include NaCI, NaF, Urea, $CaCl_2$ etc. The entropy change of the eutectic mixture is roughly equal to the sum of those of its components.

Another way of storing heat is the use of reversible chemical reaction which involves (i) Thermochemical energy storage (ii) Thermochemical Pipeline energy transport

Some of the advantanges of this systems are high energy density (much higher than sensible or latent heat storage), storage at ambient temperature, low storage-related investment cost and potential for heat pumping and long distance energy transport.

However, the technology is still immature. Its economic and efficient systems have not been actually demonstrated for practical applications.

Generally, the desired characteristics of a thermal storage includes:-

(1) Compact, large storage capacity per unit mass and volume.

(2) High storage efficiency

(3) Heat storage medium and suitable properties in the operating tempera ture range

(4) Uniform temperature

(5) Capacity to charge and discharge with the largest heat input/output rates but without temperature gradients

(6) Complete reversibility

(7) Ability to undergo large number or charging/discharging cycles without loss of performance and storage capacity.

(8) Small self-discharging rate, that is negligible.

(9) High speed of charging and discharging

(10) Should not be corrosive

(11) No fire and toxicity hazard

(12) Inexpensive

(13) Long life

Also it should be noted that in smaller heat storage the surface area to volume ratio is large and therefore, the cost of insulating material is an important factor. Phase change storages with higher energy densities are more attractive for small storage. In larger heat storage, on the other hand, the cost of storage material is more important and sensible heat storage like water is very attractive.

The major advantages of phase change stores are their large heat storage capacity and their isothermal behaviour during the charging and discharging process (Velraj et al, 1999).

However, this project would be utilising the sensible heat storage properties of granite stones painted black to increase its rate of thermal absorption to effect the solar thermal energy storage system.

2.4 SOLAR ARCHITECTURE IN ANCIENT GREECE (FIFTH CENTURY B.C. TO THE THIRD CENTURY B.C.)

Records from Kredler and Kreith, (1981) shows that the first written account of solar energy use came from ancient greece. They were faced with the problem off extreme cold in the winter. They did not have any mechanism for cooling their homes in the extreme heat of summer, nor did they have any adequate heating system for the cold winter. They frequently used kitchen stoves fueled by wood and portable brazier fueled by charcoal for heat.

By the fifth century B.C., wood and charcoal had become very scarce. The Greeks, having consumed most of their domestic supply, depended more and more on costly imports from Macedonia and Thrace, Black sea reign (chiefly Bithynia), eastern Mediterranean (the coast of Asia minor, Phoenicia and Cyprus) and southern Italy.

During this time (Hellenic period), it became popular to utilize the sun's energy for both heating and cooling buildings. The Greek developed basic principles of solar architectural design. Aeschyluis, Aristole, and Xenophon outlined principles of using the sun's heat in winter. They pointed out that the main rooms of a house should face south and the north side of the building should be sheltered from the cold winds. To minimise solar heat gain in summer, eaves on the south side should provide shade to keep out the hot sun.

The 'OLYNTHIAN HOUSE' in the city of ancient Greece is an example of solar architectural design that illustrate how solar architectural theory was translated into practice. Other excavations at Colophon, Decos, and Priene suggest that similar techniques prevailed throughout most of the country.

The typical Olynthian home was rectangular in shape. The north wall had few window openings (windows during Greek times were not covered with glass, for transparent glass had not yet been invented) and the main rooms occupied the north wing. They faced an area on the south side of the building called the 'pastas'. The pastas extended east-west across the entire width of the building and the centre section consisted of a colonnade which led into the open air courtyard.

Olynthian lies at about 400° north lattitude. With the noon elevation of the sun at the winter solstice about 26° 30' sunlight streamed through the courtyard and the pastas and into the main living rooms. To help retain the solar heat, the floors of the rooms generally were made of earth. The walls were usually adobe, a poor conductor of heat and therefore a good insulator.

2.5 SOLAR HEATED HOMES, BATHS AND GREEN HOUSES IN ROME

Like Greece, Rome also depleted fuel resources at a voracious pace. For example at a short distance from Rome, Monte Cimino was a densely forested region up to the Third century B.C.. Rome had to import pine and other types of wood from as far east as Cavcasia Fuel consumption continue to rise with the standard of living. By the first century A.D., many of the wealthier citizens enjoyed central heating.

The three most influential Roman architects namely Vitruvius, Palladius and Faventinus emphasized proper solar orientation of private villas and public baths. They wrote that rooms primarily used in winter, as well as bathing areas, should face south or southwest. Architectural evidence demonstrates that builders followed these recommendations wherever possible. The most detailed account of the construction and use of villas during the second century A.D. is contained in the letter of Pliny the young. He described how all the winter rooms in Pliny's villa faced the winter sun (Krelder and Kreith, 1981)

The Romans also went beyond techniques of passive solar building design i.e simply optimizing the solar energy exposive of a structure. They developed more sophisticated methods of exploiting solar energy including the use of glass as a solar heat trap and use of several kinds of solar heat storage.

The Romans also invented window glass in the first century A.D. but only conjectures about its degree of transmittance have been made. Later they used glass for varieties of solar collectors and storages.

With these the Roman law took into account the sun rights of its citizens. By the second century A.D. it had become a civil offence for any one to place an object in such a way that it obstructed the solar exposure of a structure which required access to the sun's energy. Solar heating must have become a common practice to provoke the enactment of such law (Kredler and Kreith, 1981)

2.6 DEVELOPMENT OF SOLAR HOT-BOXES

1767 Horace de saussure, a Swiss naturalist, begain to test the effectiveness of glass as a solar heat trap. He built five glass boxes, each a cube cut in half parallel to its bases. The sides of the first box measured 30.48 cm wide and 25.4 cm high, the second box measured 25.4 cm wide x 12.70 cm high and so forth, to the fifth and smallest box which had sides 10.16 x 50.08 cm.

The bases were cut out so that each box could be stacked one inside the other. They were attached to a table made of black pearwood.

He exposed the set of glass boxes to the sun. He found that the temperature of the largest box rose the least, and in each succeeding box the temperature increased.

The smallest box reached 87.5°C (189.5°F). Observing that the boxes tended to lose heat by convection, he improved their insulation.

The second device construction was a box made out of pine 1.27 cm ($^1/_2$ inch) thick. It measured 30.48 cm wide x 22.86 cm high per side. The interior was lined with black cork 254 cm. The three glass covers were placed 3.8cm apart. When De saussure exposed the device to the sun, he obtained a temperature of 109°C (228.2°F) or 9°C above the boiling point of water. He called it a hot-box and thus the prototype of the flat-plate solar collector was born.

Despite its superior design, the hot-box lost some heat. To correct this De Sassure place the hot-box in a large container filled with cotton wool as insulator. The container had an open top, upon exposure to sun, the temperature inside the hot-box rose to 110°C (230°F) even though the weather was not as favourable as during prior experiments.

As a third measure to eliminate heat loss, he put the hot-box into a glass covered tin box. As the sun heated the hot-box, De Saussure heated the tin box by conventional means. He was careful always to keep the outer box slightly cooler than the inner one. Using this method, he recorded a temperature of 160°C (320°F) inside the hot-box.

He did not try to improve the seal on the hot-box by adding more glass covers. He realized that what heat might have conserved would have been offset by increased absorption, reflection and dispersion of incoming sunlight by extra layers of glass (Kredler and Kreith, 1981).

Prominient 19th century scientist substantiated the results of De Saussure's hot-box experiments. Among them was Sir John Hershel, a noted British astronomer. Herschel reported that during an expedition to Cape Town South Africa, he built a small hot-box out of mahogany with a blackened interior and a single sheet of glass on top. Exposing the box perpendicular to sun, he observed that a thermometer inside rose to 65°C (149°F). When he improved the insulation of the box by heaping sand around the sides, he found that the temperature reached 80.6°C (177°F).
Herschel also placed the simple hot-box inside a large container with a glass cover. He piled sand around its outer sides, and the thermometer in the hot-box rose to 115.8°C (240.5°F) (Kredler and Kreith, 1981).

Samuel Pierpoint Langley, an American astrophysicist also testesd the effectiveness of the hot-box. He conducted his experiment in 1881 near Mt. Whitney California. He constructed a copper box with a glass top, measuring 16.5cm in diameter and 4cm deep (6.5 x 1.58 in). He placed it in a wooden box which in turn rested inside a large copper box with a glass cover, 32cm in diameter and 8cm deep (12.6 X 3.15in). Loose cotton packing filled the space between the sides of this copper box and the shell of wood enclosed the walls of the entire apparatus.

On September 9, 1881 he recorded that the innermost copper box was 113.3°C-98.5°C (235.9°F-209.3°F) hotter than outside shade temperature. These experiments proved that temperatures exceeding the boiling point of water could be obtained without the use of mirrors or other solar-focusing devices, however, no useful heat was removed from these devices (Kredler and Kreith, 1981).

2.7 STORAGE FACILITES

George Lof (1945) was the first person to use crushed rock as a storage medium. In his space heating method, he used air as the heat transfer medium. He chose air system because it eliminated the problem of freezing and the possibility of some leaks and because of its compatibility with forced air heating systems.

He intergrated this solar system with an existing conventional system in a house in Boulder, Co Thus this was also the first retrofit solar space-heating system. The house measured 93m^2 in area and the collectors occupied 43m^2. The absorber consisted of glass plates overlapped, leaving almost 0.305 m of surface exposed.

The exposed portion was painted black and the collector cover consisted of several layers of glass. The temperature of the air heated by the absorber increased by as much as 43.3°C $^{1}/_{3}$

In his storage system, he chose a pebble bed because it allowed for the maintenance of a high degree of heat stratification. A bin of gravel was located in the crawl space, measuring 5.04 m^3 in volume.

Controls allowed for the following heat modes:

(1) House cold, solar collector hot, therefore hot air from collector deliverd to the house.

(2) House hot, solar collector hot, therefore hot air from collector delivered to the house.

(3) House cold, solar collector cold, storage hot, therefore hot air from storage delivered to the house.

(4) House cold, solar collector cold, storage cold, therefore hot air from convetional heater delivered to the house. Solar energy provided about 33 percent of the homes heating load. However problems occurred with the glass absorbers, which cracked because of thermal stress (Kredler and Kreith, 1981).

In 1948 Maria Teikes, professor of Metallurgy at M.I.I., noted that solar heat storage systems based on the specific heat effect e.g. system using water or rock for storage had drawbacks when used for space heating. Providing than 2-day storage capacity when using water as the medium or 1 days when using gravel required a storage area too large to be economically feasible. Teikes substituted a solar storage system based on heat of fussion. She used Glausber's salts($Na_2SO_4.10H_20$). The salts could store 7.3 times more heat than water at a temperature range between 26.6°C and 37.8°C (80°F and 100°F), the substantce melting point. In tests conducted at a house in Dover, MA, in 1948, Telkes used 18 collectors stood at a 90°C angle behind a double pare of glass on the second floor. A vertical collector can almost as effective during the winter heating season as a collector tilted at the most favourable angle (in this case 60°).

In addition, there was the advantage that during the summer the collector absorbed only about 43 percent as much heat penetrated the house during hot weather.

The collectors were made of thin iron plate painted black and used air as the transfer medium. This system collected an average of 4533 X 10^3JIm^2, at an efficiency of almost 40 percent.

Heat was stored in bins containing 13.3 m^3 of Glauber's salts. The bins, located on the first floor, also served as radiant heating panels which supplied sufficient heat when the temperatures, air warmed by the heat in the salts was circulated through the house. The solar system supplied 80 percent of the heating load.

However, because such a large quantity of salts was required over 292.5 kg per square metre of collectors were required. The question remains whether the salts functioned by way of heat of fussion or their specific heat (Kredler and Kreith, 1981).

2.8 SOME RESEARCHERS

R.N. Awachie of National Centre for Energy Research and Development, University of Nigeria, Nsukka, Nigeria designed and constructed a solar dryer whose collector area is 3.87 X $10^2 m^2$, the depth of the drying bed, for a close packing of crops, is 2.33 X 10^{-2}m. The height difference between inlet and outlet of air is 1 .40 m. The air circulation is by natural convention and has air change of 0.22 m^3s^1 in the chamber.

The dryer temperature was found to be above the ambient temperature by an average of 43%. Nevertherless, temperature of about 12% above ambient was obtained about noon.

The dryer was found to remove 15.3% of moisture, dry basis, in two days of 17.00 hours of effective drying with a drying factor, F of 0.85

The efficiency of the dryer is found to be 21%, it is expected to be higher when it is evaluated in August during the optimum performance of the dryer.

A noted important feature of the dryer is the chimney which is located at the top of the drying chamber. It is cylindrical, with an area of 0.0177 m^2 and height of 0.89 m. The fairly large height of the chimney serves to increase the rate of flow of air through the drier. It also act as a way of exit for the warm and moist air. The height difference between inlet air and exhaust is 1.40 m (Awachie, 1985).

I.D. Ikejiofor of the Project Development Institute, Enugu, Nigeria designed and constructed a passive solar dryer in the form of a wooden box covered with transparent perspex. Food items like fish, meat, pepper, yam chips and vegetable were dried at different months of the year. The drying of the food items in the dryer was compared with open air drying of similar items. Comparatively, drying with the solar cabinet dryer showed a better result than open air drying.

In his model, the transparent top cover is of perspex, plastic or glass with a total surface area of 2.28 m^2 from which the dryer receives its insolation. The dryer cabinet is made of 3/4 inch plywood, with a volume of 1 .77 m^3. The front is higher than the rear giving the cover an inclination of about 100^0. This inclination is to allow for easy run off of water and enhance air circulation.

The racks are placed between the lower and upper vents such that the rising hot air passes through the racks. Each rack has a spreading area of 0.5 m^2 with wire mesh floor reinforced with one inch expanded metal to accommodate both fine grains like corn and items of bigger size (Ikejiofor, 1985).

2.9 TYPES OF SOLAR DRYERS

Solar dryers have been classified in many ways. Considering the operational modes and practicality of dryers, they can be classified basically into three types (Garg and Prakash, 1997). They are:

(1) Direct or Natural convention dryers
(2) Mixed mode dryers
(3) Indirect or force circulation dryers

2.9.1 NATURAL CONVENTION OR DIRECT DRYERS

This type of dryers do not use fan or blower operated by electrical energy to pass in air into the dryer. They are low in cost and easy to operate.

However the problems with these dryers are slow drying, not much control on temperature and humidity, small quantities can be dried and some products changes colour and flavour due to direct exposure to sun.

In the simplest form, they consist of some kind of enclosure and a transparent cover. The food products gets heated due to direct absorption of heat or due to heat high temperature in the enclosure and therefore, moisture from the product evaporated and goes out by the natural circulation of air.

The cabinet dryer is an example of this kind of dryer. In its simplest form it consists of a wooden or any (material) box of certain width and length (length is generally kept as three times its width), insulated all over and covered with transparent roof.

The inside is painted black for good absorption of solar radiation. The product to be dried is kept in the trays made of wire mesh. These loaded trays are kept through an openable door provided on the rear side of the drier. There is a provision for cool air and warm to leave the drier through the lower vent and upper vent.

When the food product is placed in the trays and exposed to solar radiation, the temperature of the cabinet rises resulting in the evaporation of the product moisture. This warm moist air passes through upper vent by natural convention, creating a partial vaccum and drawing fresh air up through the lower vent. Temperature of 90°C have been recorded in this dryer when it is empty. It has been observed that this kind of dryer reduced the time from one half to one third compared to open sun drying (Garg and Prakash, 1997).

2.9.2 MIXED MODE SOLAR DRYER

In this type of dryers, the air heater without any fan is used with along drying bin. The flow of air is generally by natural circulation. In its simplest form it is made up of a simple air heater, drying chamber and tall chimney. The air heater is placed slant at angle (e.g. 30°) to drying chamber. The air heater has a lower vent or opening that allows fresh air in. As the air passes through the air heater, it gets hotter which allows it to dry the moist material in the chamber. The chimney is covered with black PVC to keep the inside air warm. There is a cap at the top of the chimney, leaving some space in between chimney top and cap to allow warm humid air to go out and protecting the product from rain and other foreign materials the height of the chimney and the hot air inside it creates a pressure difference between its top and bottom thereby creating forced movement of air through the drying chamber to the top of the chimney.

It was observed that the material in the lower dryer gets overheated and overdried while the top remained underdried. Therefore, stirring of materials and drying in thin layer is recommended.

2.9.3 FORCED OR INDIRECT SOLAR DRYER

These dryers have some kind of blower used for the circulation of air which is either operated electrically or mechanically. Such dryers are faster and more effecient. They can be used for drying large quantities of agricultural products. These forced circulation type dryers are also categorised as direct mode forced circulation type dryers and indirect mode forced circulation type solar dryers.

The direct mode forced circulation dryers are similar to the indirect natural circulation dryers except that here circulation of air is made by forced circulation and therefore, are not very efficient and not preferred. While indirect type or forced circulation dryer are very efficient, can be used at low as well as high temperatures and for drying large quantities of agricultural products. Example of these dryers include bin type, tunnel type, belt type, column type, and rotary type.

A forced circulation dryer which uses some kind of thermal storage unit, heat recovery wheel and auxiliary heating arrangement are known as solar assisted or hybrid drying systems. In such hybrid dryers there are some kind of solar air heaters, drying bin, fan or blower, auxiliary energy supply unit and a thermal storage device. Auxiliary energy may be supplied either by electric heating or by oil or gas burners and used only when the solar air heaters of the heat from the thermal storage device is not sufficient to supply the necessary energy for drying the product.

There are several storage systems but the most preferred one is the rock bed type that store heat in the form of sensible heat and performs the dual function of storing the heat and that of a heat exchanger. The storage is charged when the solar radiation is at the peak or when the drying is not required. Storage unit is put in series with the solar collectors.

CHAPTER THREE

DESIGN AND CONSTRUCTION OF THE DRYER

3.0 MATERIALS USED FOR THE CONSTRUCTION OF THE DRYER

The dryer is designed and constructed to dry cereal for both planting and for food. Examples of such are plantain, maize, groundnut. The effective temperature required for this is about (45°C-50°C). Anything above this might destroy the seedlings or embryo which might hinder germination. One-way air collectors are therefore mainly used for low temperature applications e.g. for crop drying or direct space heating. (Michael et al, 1995)

The dryer is also designed and constructed to dry meat and fish. In doing this higher temperature (60°C-70°C) is required. With this in mind, the dryer was constructed to allow low and higher temperature range to suit the desire of the user through the working of the upper vent and lower vent.

The Solar dryer was constructed with the following materials

(1.) Glass
(2.) Aluminium
(3.) Plywood
(4.) Foam
(5.) Granite pebbles
(6.) Pipe (PVC)
(7.) Wood
(8.) Black Paint
(9.) Nail
(10.) Evo-stick
(11.) Foam

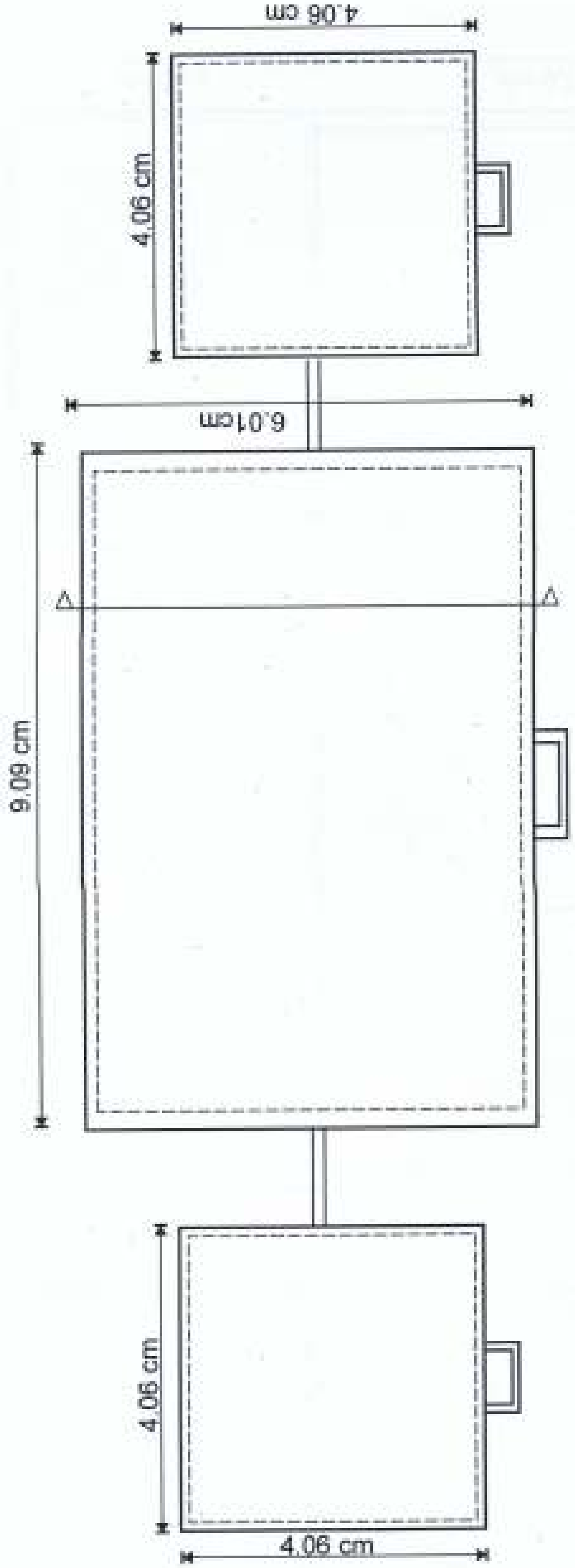
3.1 FACTORS CONSIDERED IN THE SELECTION OF THE COMPONENT OF THE DRYER

Since the main features of the dryer are the cover, absorber (receiver), drying rack, drying chambers, connecting pipes (pvc) and the pebbles (granite stones). The following factors were considered in choosing all these material so that they can be effective.

The cover must be scratch resistance, not affected by ultra-violet rays, but must have high transmittance for infrared rays. It must be durable and have sufficient thermal strength. Taken these into consideration, plastic was not used as the cover or collector. Glass was used because it possessed all the listed properties.

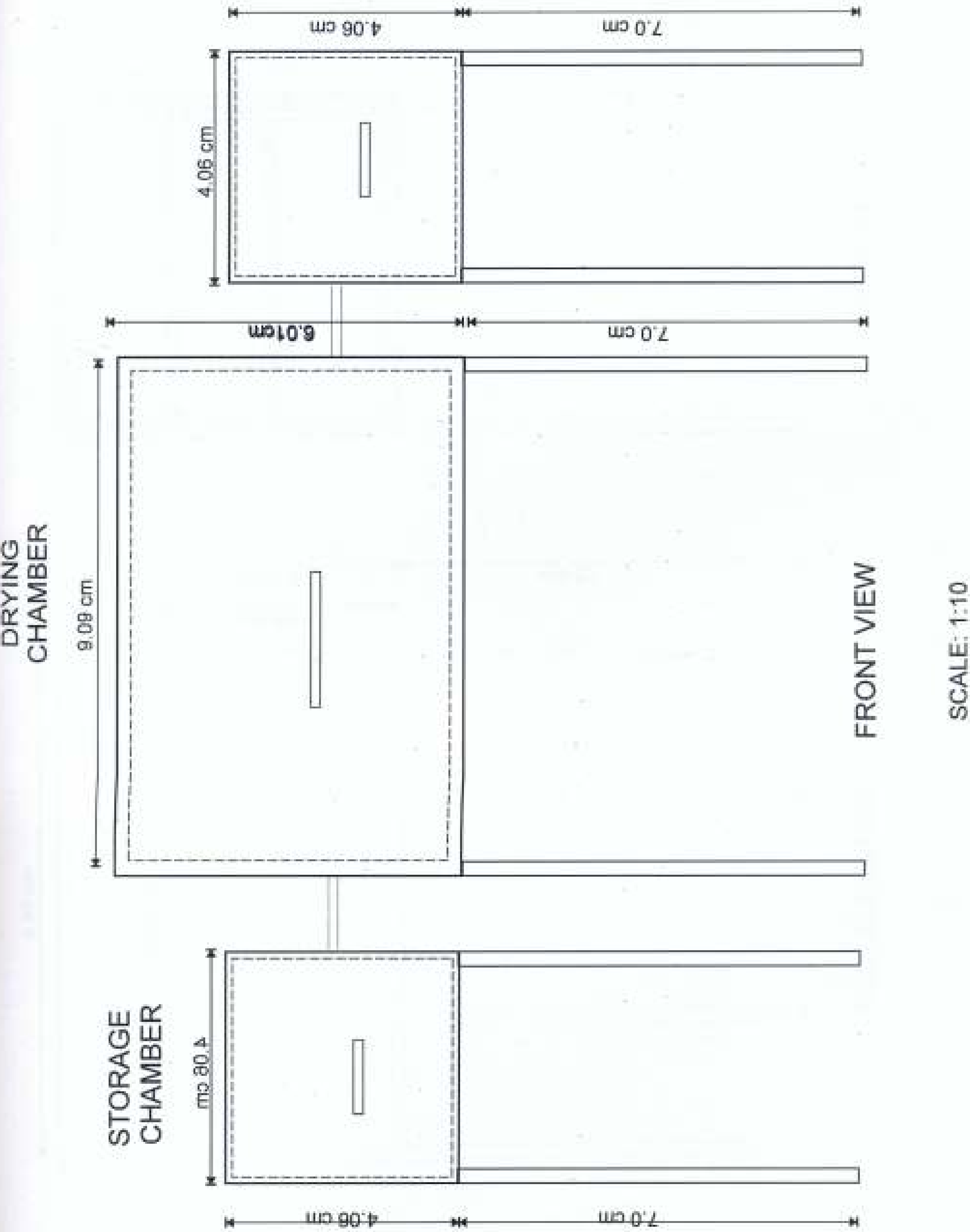
The receiver which act as the absorber must have high absorptivity for solar radiation. It should also be able to radiate all the absorbed heat into the drying chamber. Also it should resist corrosion. With these, copper is a preferred material because of its high conductivity and resistance to corrosion. But it is too expensive. Therefore, Aluminium was used even though it offers high conductivity at a low cost and its susceptibility to corrosion can be reduced since the dryer is relatively a drying chamber. Also the Aluminium plate was painted black to increase its absorptivity for solar radiation and the emission of the absorbed heat.

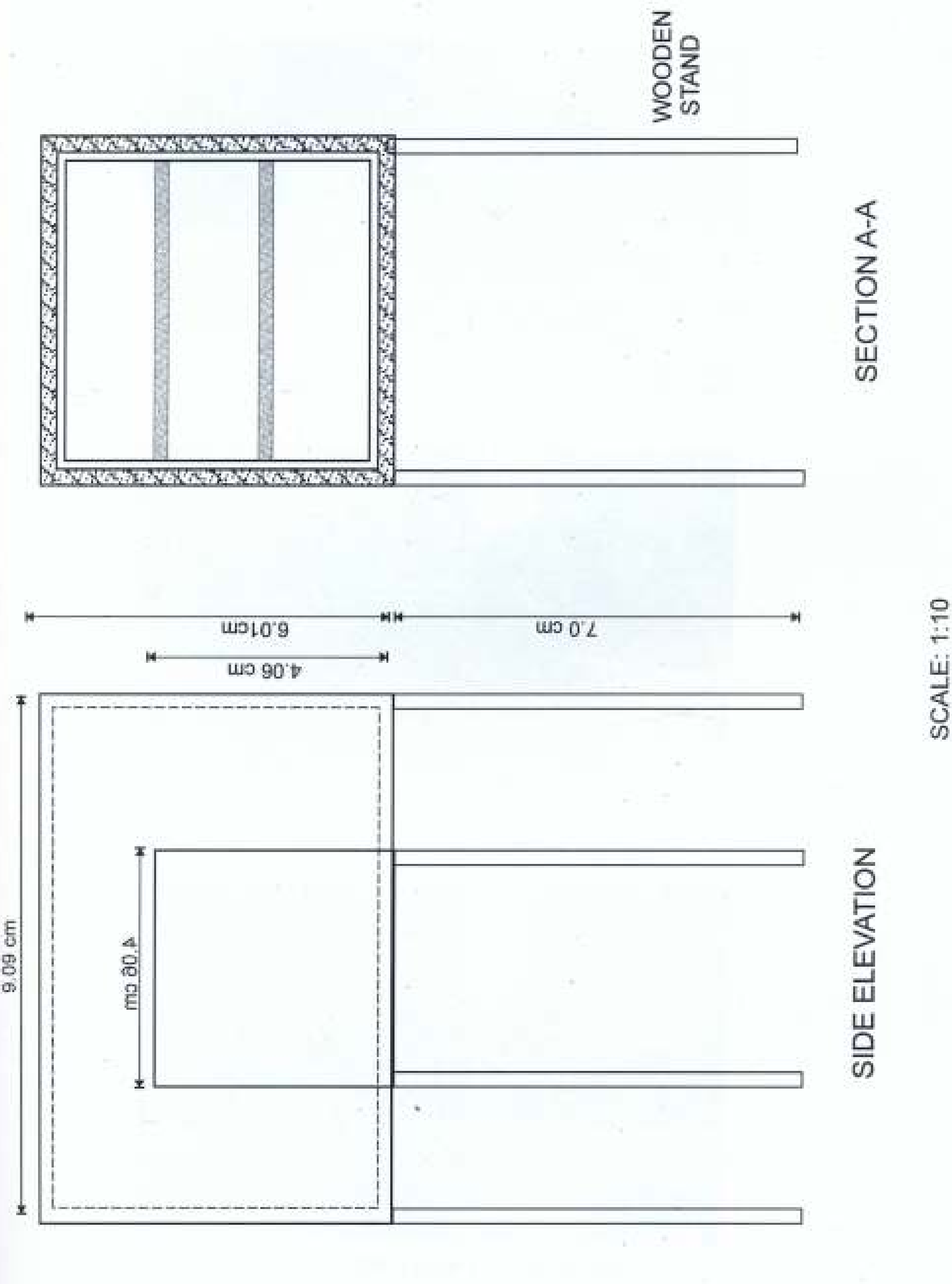
Granite pebbles painted black were used as the storage medium so that during non-solar hours the dryer can still maintain a temperature higher than the ambient temperature. Foam and plywood were used so that they can serve as insutator to prevent heat loss by the dryer. Likewise wood was selected for the frame instead of iron because it is a non-conductor of heat and hence shall ensure minimal heat loss.



PLAN VIEW

SCALE: 1:10


DRYING CHAMBER
STORAGE CHAMBER
4.06 cm
7.0 cm
6.01cm
9.09 cm
FRONT VIEW
SCALE: 1:10


WOODEN STAND
SECTION A-A
6.01cm
7.0 cm
4.06 cm
SCALE: 1:10
9.09 cm
4.06 cm
SIDE ELEVATION

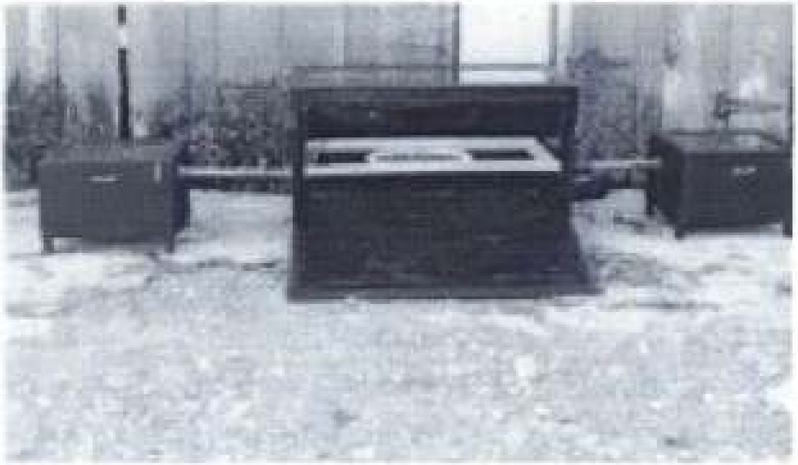


Fig 3.2a: The Dryer when loaded

Fig 3.2b: The inner Chamber of the Dryer

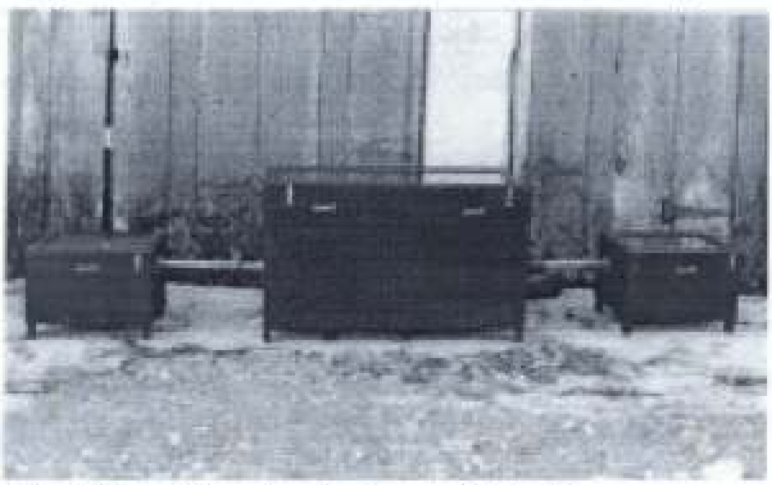


Fig 3.2c: The front view of the Dryer

3.3 FABRICATION OF THE DRYER

The frame of the dryer was made of rectangular wooden box of 90.90 cm x 60.10 cm x 60.20 cm. After the construction of the frame, it was covered on every side by the ply-wood leaving spaces for the lower and the upper vent. The frame has four legs which the dryer stand upon. The legs were 0.7 cm high.

After the ply-wood have been used to cover all the wooden frame, foam was used to line the interior of the ply-wood to serve as insulator to reduce heat loss by the dryer. After linning the box with foam, inside was linned with Aluminium plate or sheet which serves as the receiver (absorber). The Aluminium was painted black to increase its absorption and emission since black bodies has the power to absorb all the radiant heat that falls on them and at the same time emit all the absorbed heat with waves of equal wavelength.

The dryer also has a drying rack to give more space for drying. It also allows radiation from the sun to reach the bottom of the box

The glass which serves as the collector (flat plate collector) was placed lastly on the box and hold in place by a tightly fitted wood placed below and above the glass cover. The surface area of the glass is 0.909 cm x 0.601 cm.
The glass was made to be double-layer in order to effectively trap down the generated heat.

The thermal storage cabinet was 40.60 cm x 40.60 cm x 30.15 cm connected to the dryer to provide heat during non-solar hours especially in the night. Inside the storage chamber are granite pebbles painted black which absorb heat during sunshine duration and release it to the dryer when the dryer temperature falls below the storage temperature. This enhances continuous flow of heat to the samples in the dryer. This is an added advantage for effective quick drying.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 PERFORMANCE EVALUATION OF THE SOLAR DRYER

The solar dryer was used to dry plantain chips, pepper and fish. The drying was done by exposing the materials to the open sun and also in the dryer. The drying was done simultaneously with materials of equal masses. The masses of the samples were taken before drying and measured every one hour to determine the mass of the moisture loss both in the open air and in the dryer.

At the end of the process a bar chart was plotted to show the drying rates of the samples in the dryer and in the open air for all samples.

Moisture loss of the dried crop was plotted against the time of the day. Likewise the temperature of the dryer and the ambient temperature was plotted against time of the day.

The percentage loss in moisture was also computed as show below.

If X is the initial mass and Y is the final mass, then,

$$\% \text{ Loss in Moisture} = \frac{X - Y}{X} \times 100$$

This was done for both samples in the open air and in the dryer.

4.2 PRESENTATION AND ANALYSIS OF THE DRYER PERFORMANCE

Data were collected for a period of three weeks in the month of February, 2004. In the first week, data were collected to show the functioning of the solar dryer when unloaded and the solar thermal storage system over the ambient condition. Table 3.1a-e presents the temperature data. After which the average of the results were computed (Table 3.1f) and a graph (Fig. 3.1) with a bar chart (Fig.3.2) were plotted using the obtained data.

In the second week, data was collected showing efficiency of the dryer storage working together over the ambient Condition. Average of the results was also computed and a graph with a bar chart was plotted for the results.

In the third week, plantain chips, pepper and fish of equal masses were dried in the dryer and open air simultaneously. Loss in moisture and percentage loss in moisture were recorded. After which a graph and a bar chart was plotted for the two conditions.

TABLE 4.1:
DATA SHOWING THE DRYER, STORAGE AND THE AMBIENT TEMPERATURE FOR 12 HOURS

TABLE 4.1a 9/2/2004

Time Hour	T_1°C amb Temp.	T_2°C Dryer Temp.	T_3°C Storage Temp.
9.00a.m	26.0	26.0	26.0
10.00a.m	28.0	47.0	28.0
11.00a.m	31.0	62.0	36.0
12.00p.m	33.0	71.0	46.0
1.00p.m	34.0	75.0	54.0
2.00p.m	34.0	76.0	58.0
3.00p.m	33.0	63.0	59.0
4.00p.m	33.5	62.0	59.0
5.00p.m	32.5	52.0	57.0
6.00p.m	30.5	38.0	52.0
7.00p.m	29.5	32.0	47.0
8.00p.m	28.5	28.5	43.0
9.00p.m	26.5	26.5	39.0

TABLE 4.1b 10/2/2004

Time Hour	T_1°C amb. Temp.	T_2°C Dryer Temp.	T_3°C Storage Temp.
9.00a.m	25.0	33.0	26.0
10.00a.m	28.0	49.0	30.0
11.00a.m	30.0	59.0	39.0
12.00p.m	32.0	69.0	41.0
1.00p.m	34.0	73.0	48.0
2.00p.m	35.0	74.0	54.0
3.00p.m	34.0	72.0	48.0
4.00p.m	34.5	64.0	58.0
5.00p.m	33.5	50.0	57.0
6.00p.m	32.5	40.0	52.0
7.00p.m	30.0	34.0	50.0
8.00p.m	29.5	30.0	44.5
9.00p.m	28.5	29.0	42.0

TABLE 4.1c 11/2/2004

Time Hour	T_1°C amb Temp	T_2°C Dryer Temp	T_3°C Storage Temp
9.00a.m	26.0	23.0	26.0
10.00a.m	26.0	48.0	28.0
11.00a.m	28.0	62.0	35.0
12.00p.m	31.0	72.0	44.0
1.00p.m	31.0	74.0	55.0
2.00p.m	32.0	75.0	57.0
3.00p.m	34.0	70.0	59.0
4.00p.m	33.0	64.0	59.0
5.00p.m	31.0	51.0	57.0
6.00p.m	30.5	38.0	52.0
7.00p.m	29.0	32.0	47.0
8.00p.m	28.0	29.0	43.0
9.00p.m	27.0	28.0	39.0

TABLE 4.1d 12/2/2004

Time Hour	T_1°C amb Temp	T_2°C Dryer Temp	T_3°C Storage Temp
9.00a.m	25.0	34.0	26.0
10.00a.m	28.0	48.0	30.0
11.00a.m	30.0	57.0	38.0
12.00p.m	31.0	68.0	40.0
1.00p.m	33.0	74.0	48.0
2.00p.m	34.0	72.0	57.0
3.00p.m	34.0	72.0	59.0
4.00p.m	33.5	63.0	58.0
5.00p.m	32.5	51.0	57.0
6.00p.m	31.5	41.0	51.0
7.00p.m	30.5	35.0	50.0
8.00p.m	30.0	31.0	43.5
9.00p.m	29.5	30.0	41.0

TABLE 4.1e 13/2/2004

Time Hour	T_1°C amb Temp	T_2°C Dryer Temp	T_3°C Storage Temp
9.00a.m	26.0	28.0	27.0
10.00a.m	28.0	48.0	30.0
11.00a.m	31.0	63.0	36.0
12.00p.m	33.0	71.0	46.0
1.00p.m	34.0	75.0	54.0
2.00p.m	34.0	75.0	54.0
3.00p.m	33.0	74.0	57.0
4.00p.m	33.0	62.0	58.0
5.00p.m	32.5	52.0	59.0
6.00p.m	32.5	38.0	52.0
7.00p.m	30.0	32.0	50.0
8.00p.m	29.5	30.0	44.0
9.00p.m	28.5	29.0	40.0

TABLE 4.1f
AVERAGE DATA FOR THE FIVE DAYS

Time Hour	T_1°C amb Temp	T_2°C Dryer Temp	T_3°C Storage Temp
9.00a.m	25.6	30.8	26.2
10.00a.m	27.6	48.0	29.2
11.00a.m	30.0	60.6	36.8
12.00p.m	32.0	70.2	43.4
1.00p.m	33.2	74.2	50.6
2.00p.m	33.8	75.1	55.4
3.00p.m	33.6	70.2	57.8
4.00p.m	33.5	63.4	58.4
5.00p.m	32.4	51.2	56.2
6.00p.m	31.5	39.0	51.8
7.00p.m	29.8	33.0	48.8
8.00p.m	29.1	29.7	43.6
9.00p.m	28.0	28.5	40.2

From the data (Table 4.1, Fig. 4.1 and 4.2) it can be seen that the solar dryer has very wide temperature gradient as against the ambient temperature especially between 11.00a.m and 6.00p.m. By 11.00a.m. the solar dryer temperature has doubled that of ambient temperature. By 2.00p.m when the dryer and ambient temperature are both at their peak, the dryer's temperature is 122% above the ambient temperature. With these, the dryer can function very well as a drying machine.

Also, from the data, the storage temperature though rise slowly but still conserve heat. The rate at which it dissipates heat out during low solar radiation between (3.00p.m – 9.00p.m) is low compare to dryer that loss its heat drastically. By 5.00p.m the storage has a temperature margin as against the dryer. Therefore, the storage can be implemented with the dryer so that the dryer's temperature can be higher than that of the ambient always even during low solar hours (i.e between 5.00p.m – 9.00p.m).

With these it is obvious that the dryer and the storage when use together will function very well as a drying machine as compare to open air drying which is very slow due to low temperature and prone to destruction and eating by pest and rodents. Also it produces hygienic food and products than open air drying.

TABLE 4.2

DATA SHOWING THE DRYER WITH STORAGE AND AMBIENT TEMPERATURE FOR 12 HOURS (9.00a.m - 9.00p.m) FOR FIVE DAYS

TABLE 4.2a 14/2/2004

Time Hour	T_4°C amb Temp	T_5°C Dryer with Storage Temp
9.00a.m	26.0	37.0
10.00a.m	28.5	49.0
11.00a.m	30.5	60.0
12.00p.m	34.0	69.0
1.00p.m	34.5	74.5
2.00p.m	35.0	75.0
3.00p.m	36.0	73.0
4.00p.m	35.5	65.0
5.00p.m	34.5	56.0
6.00p.m	32.5	45.0
7.00p.m	31.0	36.0
8.00p.m	29.0	33.0
9.00p.m	28.0	30.0

TABLE 4.2b 15/2/2004

Time Hour	T_4°C amb Temp	T_5°C Dryer with Storage Temp
9.00a.m	27.0	35.0
10.00a.m	29.0	50.0
11.00a.m	30.5	58.0
12.00p.m	32.0	69.0
1.00p.m	34.0	73.0
2.00p.m	34.0	73.0
3.00p.m	36.0	73.0
4.00p.m	35.5	64.0
5.00p.m	34.0	54.5
6.00p.m	31.0	38.0
7.00p.m	31.0	38.0
8.00p.m	29.0	34.0
9.00p.m	27.0	31.0

TABLE 4.2c 16/2/2004

Time Hour	T_4°C amb Temp	T_5°C Dryer with Storage Temp
9.00a.m	25.0	34.0
10.00a.m	28.0	49.0
11.00a.m	30.0	58.0
12.00p.m	32.0	69.0
1.00p.m	34.0	74.0
2.00p.m	34.0	74.0
3.00p.m	33.0	73.5
4.00p.m	32.0	64.0
5.00p.m	30.5	57.0
6.00p.m	29.0	46.0
7.00p.m	28.5	37.0
8.00p.m	28.0	34.0
9.00p.m	27.0	31.0

TABLE 4.2d 17/2/2004

Time Hour	T_4°C amb Temp	T_5°C Dryer with Storage Temp
9.00a.m	25.0	35.0
10.00a.m	28.0	51.0
11.00a.m	30.0	59.0
12.00p.m	31.0	68.0
1.00p.m	32.0	74.5
2.00p.m	34.0	75.0
3.00p.m	33.0	75.0
4.00p.m	33.0	66.0
5.00p.m	31.0	57.0
6.00p.m	30.5	47.0
7.00p.m	29.0	39.0
8.00p.m	28.0	34.0
9.00p.m	27.0	31.0

TABLE 4.2e 18/2/2004

Time Hour	T_4°C amb Temp	T_5°C Dryer with Storage Temp
9.00a.m	26.0	36.0
10.00a.m	28.0	49.0
11.00a.m	31.0	58.0
12.00p.m	33.0	69.0
1.00p.m	34.0	73.5
2.00p.m	34.0	74.0
3.00p.m	33.0	74.0
4.00p.m	33.0	63.5
5.00p.m	31.0	54.5
6.00p.m	30.5	45.0
7.00p.m	29.0	39.0
8.00p.m	28.0	35.0
9.00p.m	27.0	32.0

TABLE 4.2f:
Average Data for the five days.

Time Hour	T_4°C amb Temp	T_5°C Dryer with Storage Temp
9.00a.m	25.8	35.4
10.00a.m	28.3	49.6
11.00a.m	30.4	58.0
12.00p.m	32.4	68.8
1.00p.m	33.7	73.9
2.00p.m	34.2	74.2
3.00p.m	34.2	73.7
4.00p.m	32.8	64.5
5.00p.m	32.2	55.8
6.00p.m	31.1	45.8
7.00p.m	29.7	37.8
8.00p.m	28.4	34.0
9.00p.m	27.2	31.0

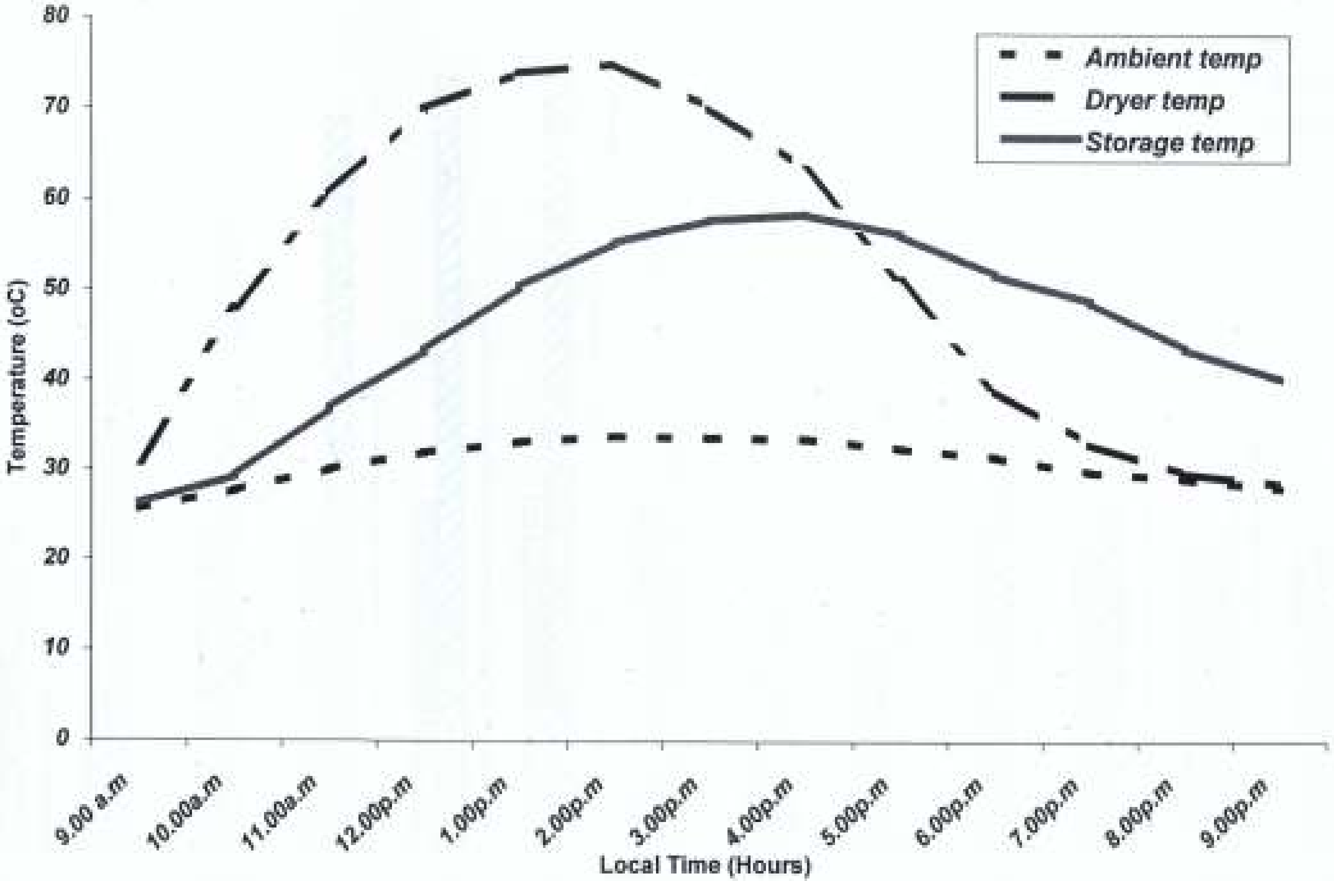


Fig. 4.1:- A plot of Average temperature of the dryer, storage and ambient against time

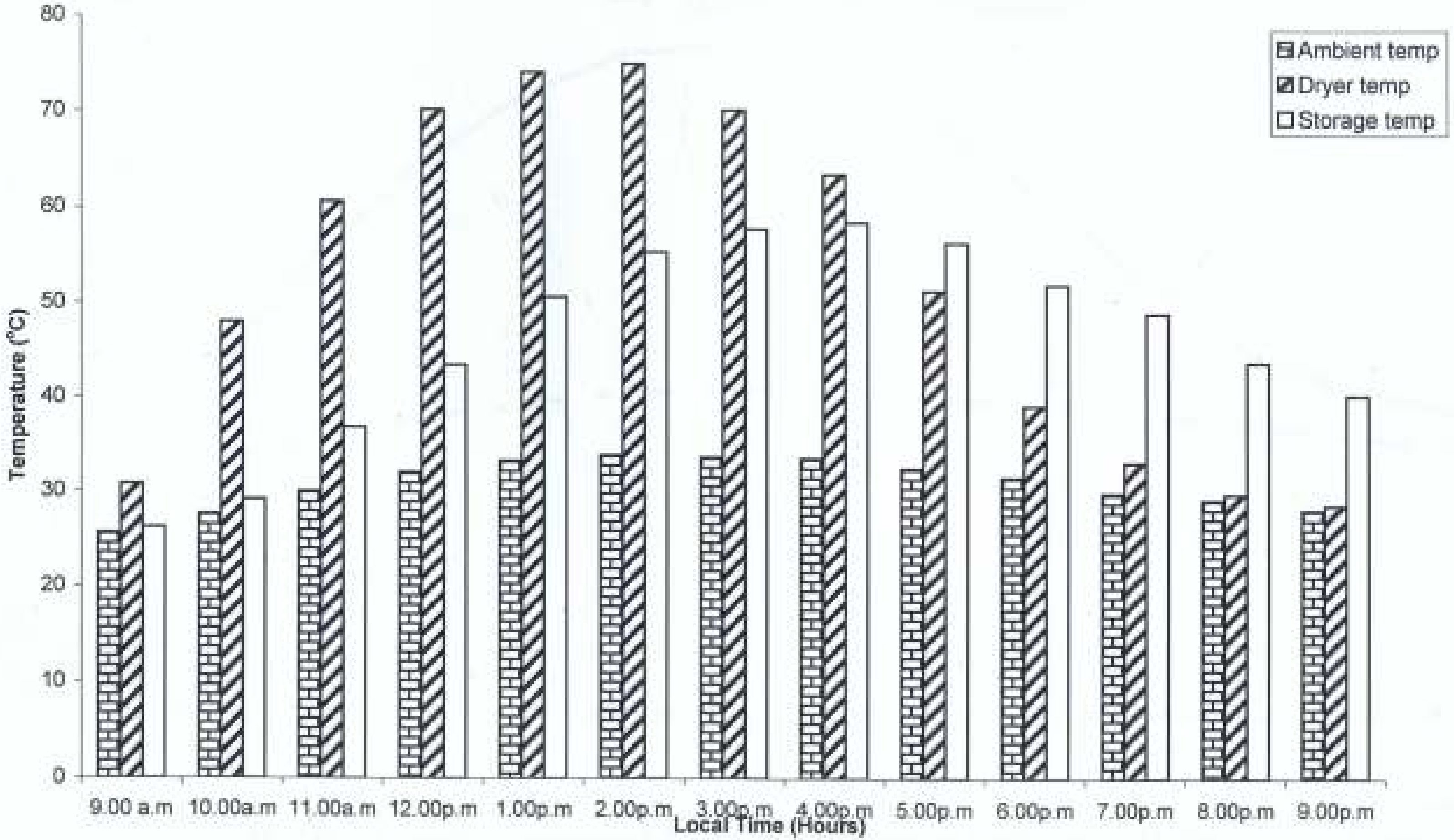


Fig. 4.2:- A bar chart showing Average Temperature of the dryer, Storage and Ambient against time

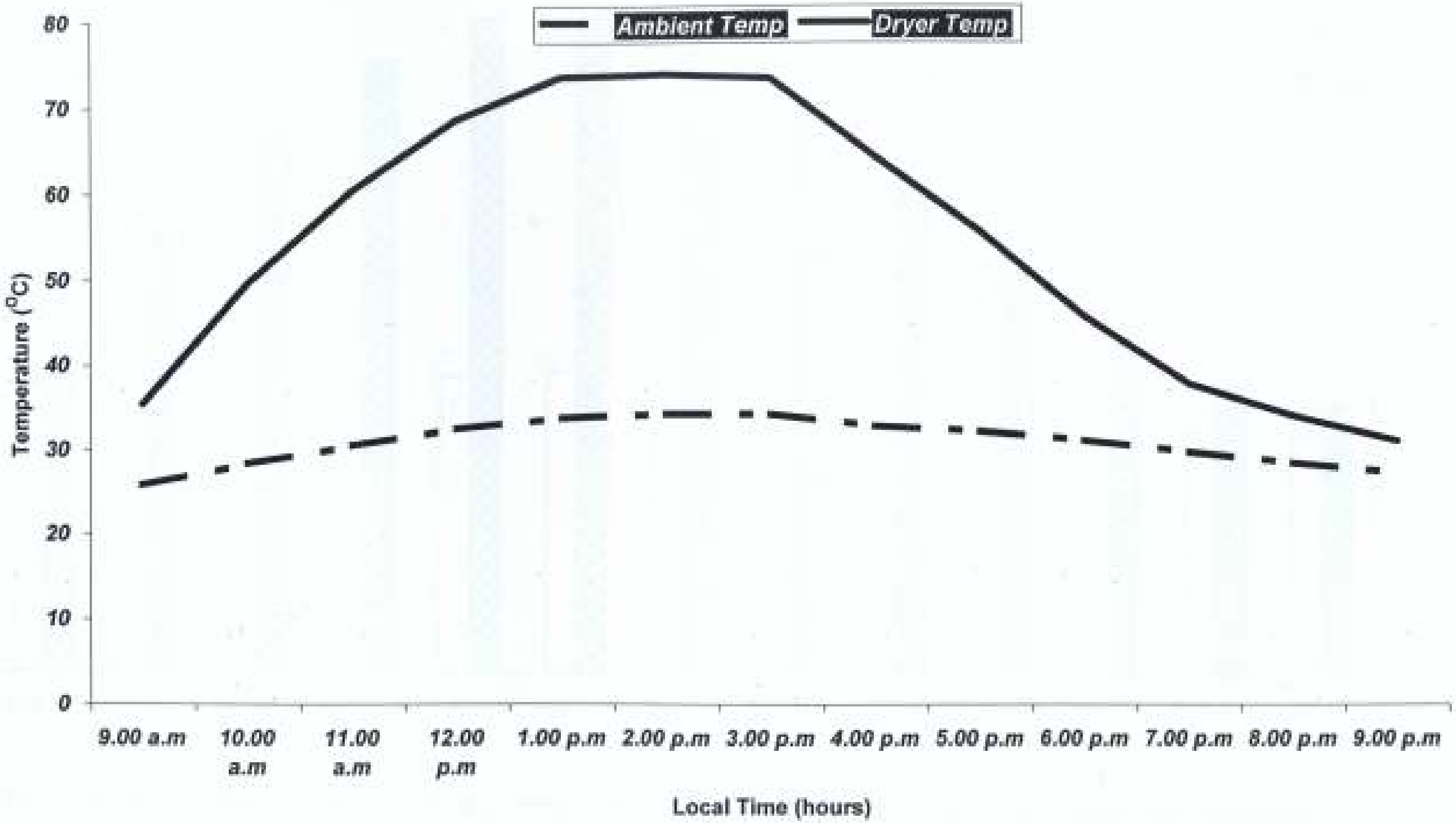


Fig.4.3:- A graph of average temperature of storage implemented with dryer and ambient against time

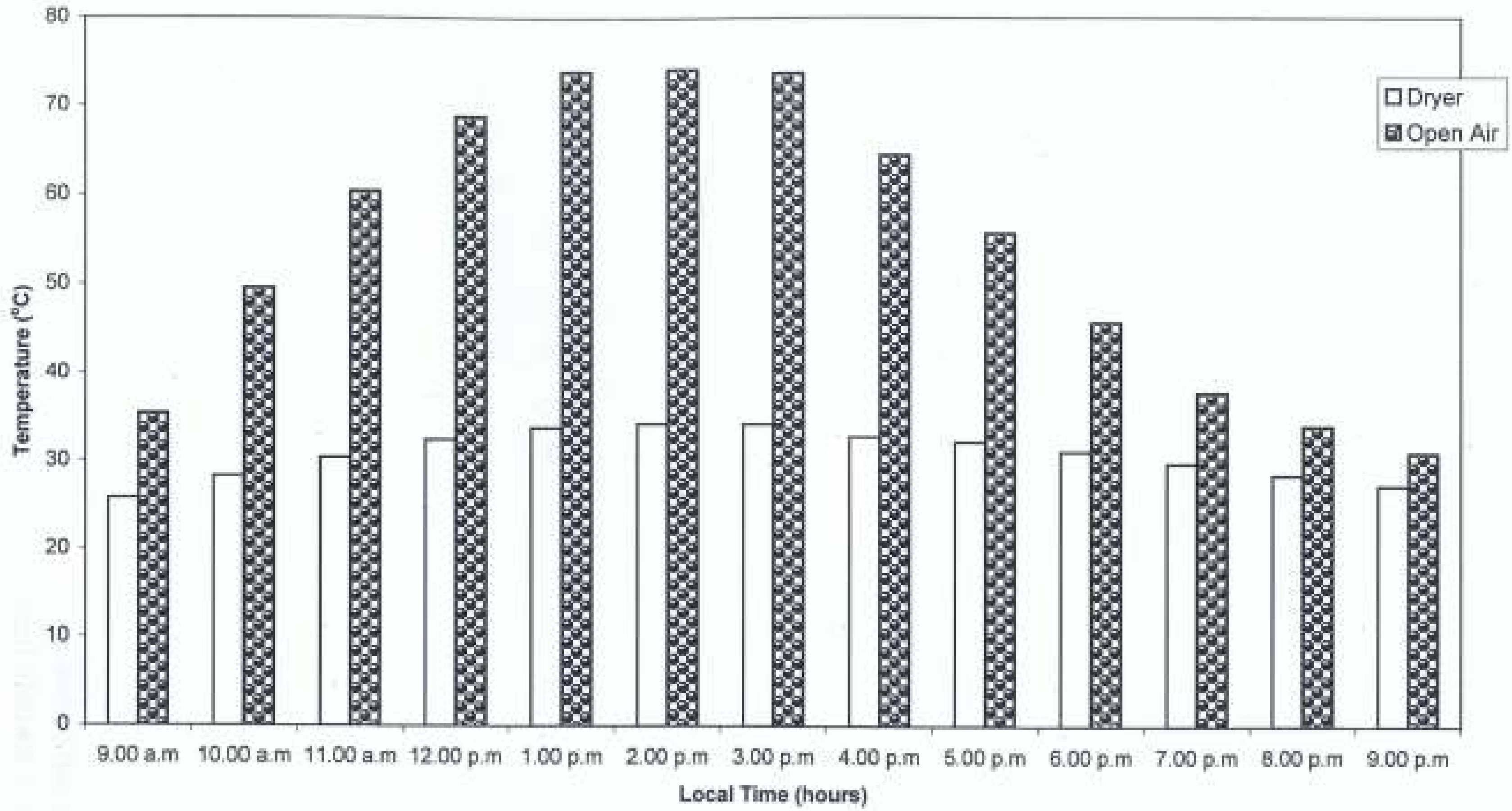


Fig. 4.4:- A bar chart showing average temperature of storage implemented with dryer and ambient against time

From the data Table 4.2a - 4.2f and Fig. 4.1 - Fig 4.3, it can be seen again that the solar dryer implemented with storage still has a very high temperature margin as against the ambient temperature always.

Therefore, the storage integrated with dryer can function very well as a drying machine than ordinary open air.

SAMPLE 1: PLANTAIN CHIPS

TABLE 4.3: Table showing the data collected for sample 1 on the 24th and 25th February, 2004.

24/2/2004

Time Hour	OPEN AIR				DRYER			
	Temp °C	Mass kg	Loss in moisture kg	% Loss in moisture	Temp °C	Mass kg	Loss in moisture kg	% Loss in moisture
10.00a.m	31.5	1.00	-	-	47.0	1.00	-	-
11.00a.m	32.0	0.96	0.04	4.0	58.0	0.95	0.05	5.0
12.00p.m	34.0	0.92	0.18	8.0	65.0	0.90	0.10	10.0
1.00p.m	36.5	0.83	0.17	17.0	70.0	0.82	0.18	18.0
2.00p.m	37.0	0.78	0.22	22.0	72.0	0.72	0.28	28.0
3.00p.m	37.5	0.75	0.25	25.0	62.5	0.66	0.34	34.0
4.00p.m	36.5	0.72	0.28	28.0	58.0	0.62	0.38	38.0
5.00p.m	35.0	0.70	0.30	30.0	50.0	0.60	0.40	40.0
6.00p.m	33.0	0.70	0.30	30.0	47.0	0.58	0.42	42.0
7.00p.m	32.0	0.70	0.31	31.0	45.0	0.56	0.44	44.0

25/02/2004

Time Hour	OPEN AIR				DRYER			
	Temp °C	Mass kg	Loss in moisture kg	% Loss in moisture	Temp °C	Mass kg	Loss in moisture kg	% Loss in moisture
10.00a.m	31.0	0.65	0.35	35.0	48.0	0.52	0.48	48.0
11.00a.m	32.0	0.64	0.36	36.0	54.0	0.50	0.50	50.0
12.00p.m	34.0	0.62	0.38	0.38	56.0	0.48	0.52	52.0
1.00p.m	35.5	0.69	0.41	41.0	58.0	0.43	0.57	57.0
2.00p.m	36.0	0.55	0.45	45.0	58.0	0.38	0.62	62.0
3.00p.m	35.0	0.53	0.47	47.0	56.0	0.35	0.65	65.0
4.00p.m	32.0	0.51	0.49	49.0	50.0	0.34	0.66	66.0
5.00p.m	32.0	0.50	0.50	50.0	48.0	0.33	0.67	67.0
6.00p.m	31.0	0.50	0.50	50.0	45.0	0.32	0.68	68.0
7.00p.m	29.0	0.50	0.50	50.0	36.0	0.31	0.69	69.0

SAMPLE II: PEPPER

TABLE 4.4:- Table showing the data collected for sample II on the 26th and 27th February, 2004

26/2/2004

Time Hour	OPEN AIR				DRYER			
	Temp °C	Mass kg	Loss in moisture kg	% Loss in moisture	Temp °C	Mass Kg	Loss in moist. Kg	% Loss in moist.
10.00a.m	29.0	0.80	-	-	38.0	0.80	-	-
11.00a.m	32.0	0.77	0.03	3.75	47.0	0.76	0.04	5.00
12.00p.m	33.0	0.75	0.05	6.25	53.0	0.70	0.10	12.50
1.00p.m	34.0	0.72	0.08	10.00	54.0	0.62	0.18	22.50
2.00p.m	35.0	0.69	0.11	13.75	57.0	0.57	0.23	28.75
3.00p.m	34.0	0.66	0.14	17.50	56.0	0.53	0.27	33.75
4.00p.m	33.0	0.64	0.16	20.00	50.0	0.48	0.32	40.0
5.00p.m	33.5	0.62	0.18	22.50	45.0	0.45	0.35	43.75
6.00p.m	32.0	0.62	0.18	22.50	42.0	0.44	0.36	45.00
7.00p.m	29.0	0.62	0.18	22.50	38.0	0.43	0.37	46.25

27/2/ 2004

Time Hour	OPEN AIR				DRYER			
	Temp °C	Mass kg	Loss in moisture kg	% Loss in moisture	Temp °C	Mass kg	Loss in moisture kg	% Loss in moisture
10.00a.m	29.0	0.61	0.19	23.75	39.0	0.44	0.39	48.75
11.00a.m	30.0	0.60	0.20	25.00	47.0	0.39	0.41	51.25
12.00p.m	32.0	0.58	0.22	27.50	52.0	0.36	0.44	55.00
1.00p.m	34.5	0.56	0.24	30.00	57.0	0.32	0.48	60.00
2.00p.m	34.5	0.53	0.27	33.75	59.5	0.28	0.52	65.00
3.00p.m	35.0	0.52	0.28	35.00	58.5	0.25	0.55	68.75
4.00p.m	34.0	0.50	0.30	37.50	63.0	0.23	0.57	71.25
5.00p.m	33.0	0.49	0.31	38.75	50.0	0.21	0.59	73.75
6.00p.m	32.0	0.48	0.32	40.00	45.0	0.20	0.60	75.00
7.00p.m	30.0	0.48	0.32	40.00	40.0	0.19	0.61	76.25

SAMPLE III: FISH

TABLE 4.5 TABLE SHOWING DATA COLLECTED FOR SAMPLE III on the 28th and 29th February, 2004

28/2/2004

Time Hour	OPEN AIR				DRYER			
	Temp °C	Mass kg	Loss in moisture kg	% Loss in moisture	Temp °C	Mass kg	Loss in moisture kg	% Loss in moisture
10.00a.m	29.0	0.30	-	-	39.0	0.30	-	-
11.00a.m	30.0	0.30	-	-	46.0	0.29	0.01	3.33
12.00p.m	32.0	0.29	0.01	3.33	62.0	0.28	0.20	6.67
1.00p.m	33.0	0.28	0.02	6.67	70.0	0.26	0.04	13.33
2.00p.m	34.0	0.28	0.02	6.67	72.0	0.24	0.06	20.00
3.00p.m	33.5	0.28	0.02	6.67	60.0	0.22	0.08	26.67
4.00p.m	32.0	0.27	0.03	10.00	55.0	0.21	0.09	30.00
5.00p.m	30.0	0.27	0.03	10.00	46.0	0.20	0.10	33.33
6.00p.m	29.0	0.26	0.04	13.33	41.0	0.20	0.10	33.33
7.00p.m	28.0	0.26	0.04	13.33	39.0	0.19	0.11	36.67

29/2/2004

Time Hour	OPEN AIR				DRYER			
	Temp °C	Mass kg	Loss in moisture kg	% Loss in moisture	Temp °C	Mass kg	Loss in moisture kg	% Loss in moisture
10.00a.m	30.0	0.25	0.05	16.67	40.0	0.18	0.12	40.00
11.00a.m	30.5	0.25	0.05	16.67	45.0	0.17	0.13	43.33
12.00p.m	32.0	0.24	0.06	20.00	61.0	0.16	0.14	46.67
1.00p.m	33.0	0.24	0.06	20.00	71.0	0.14	0.16	53.33
2.00p.m	34.0	0.23	0.07	23.33	72.5	0.11	0.19	63.33
3.00p.m	33.5	0.23	0.07	23.30	60.0	0.10	0.20	66.67
4.00p.m	31.5	0.22	0.08	26.67	56.0	0.09	0.21	70.00
5.00p.m	30.0	0.22	0.08	26.67	46.0	0.08	0.22	73.33
6.00p.m	29.0	0.21	0.09	30.00	40.0	0.08	0.22	73.33
7.00p.m	28.5	0.21	0.09	30.00	38.5	0.07	0.23	76.67

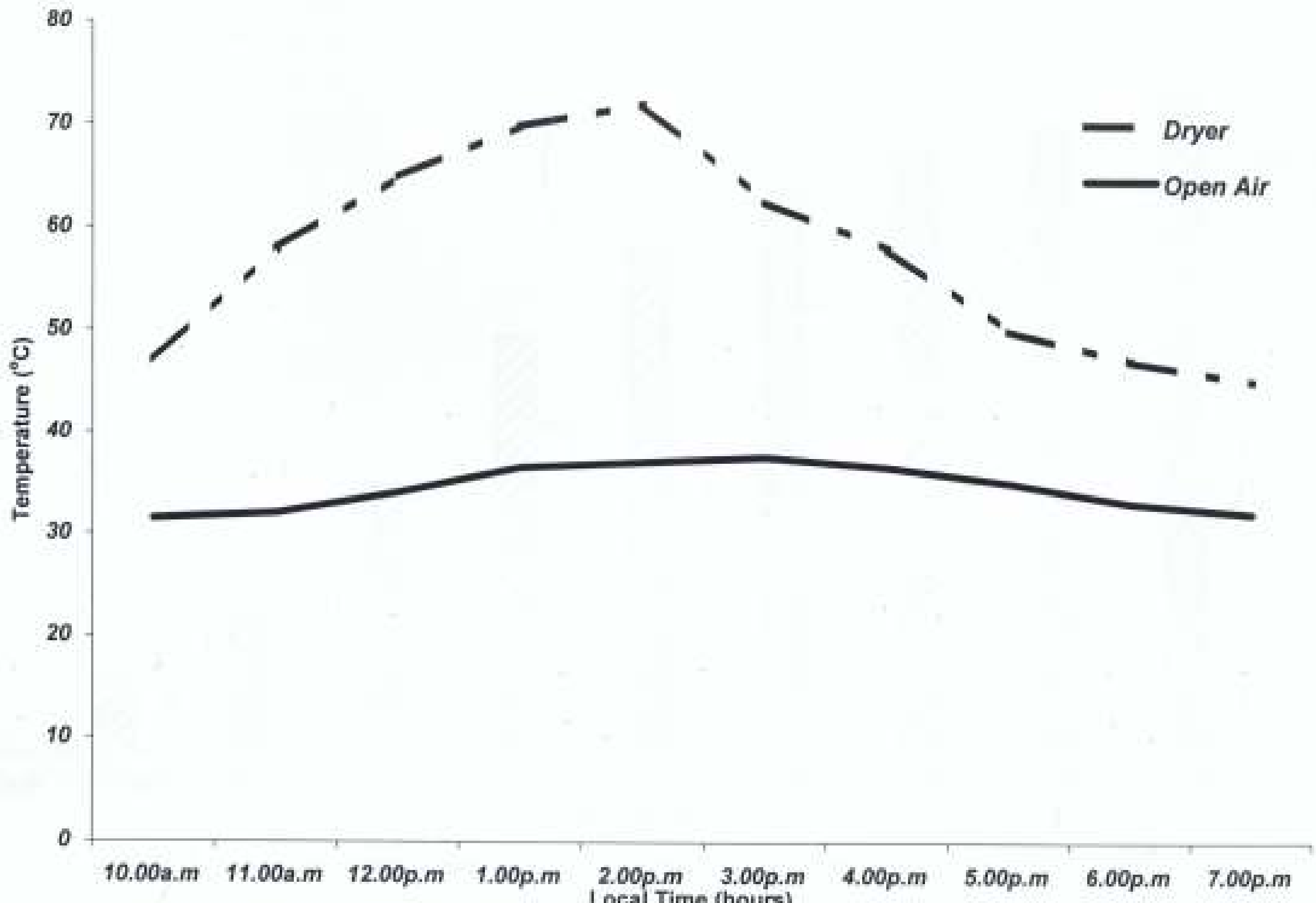


Fig. 4.5: A plot of temperature against time for sample I 24/02/2004

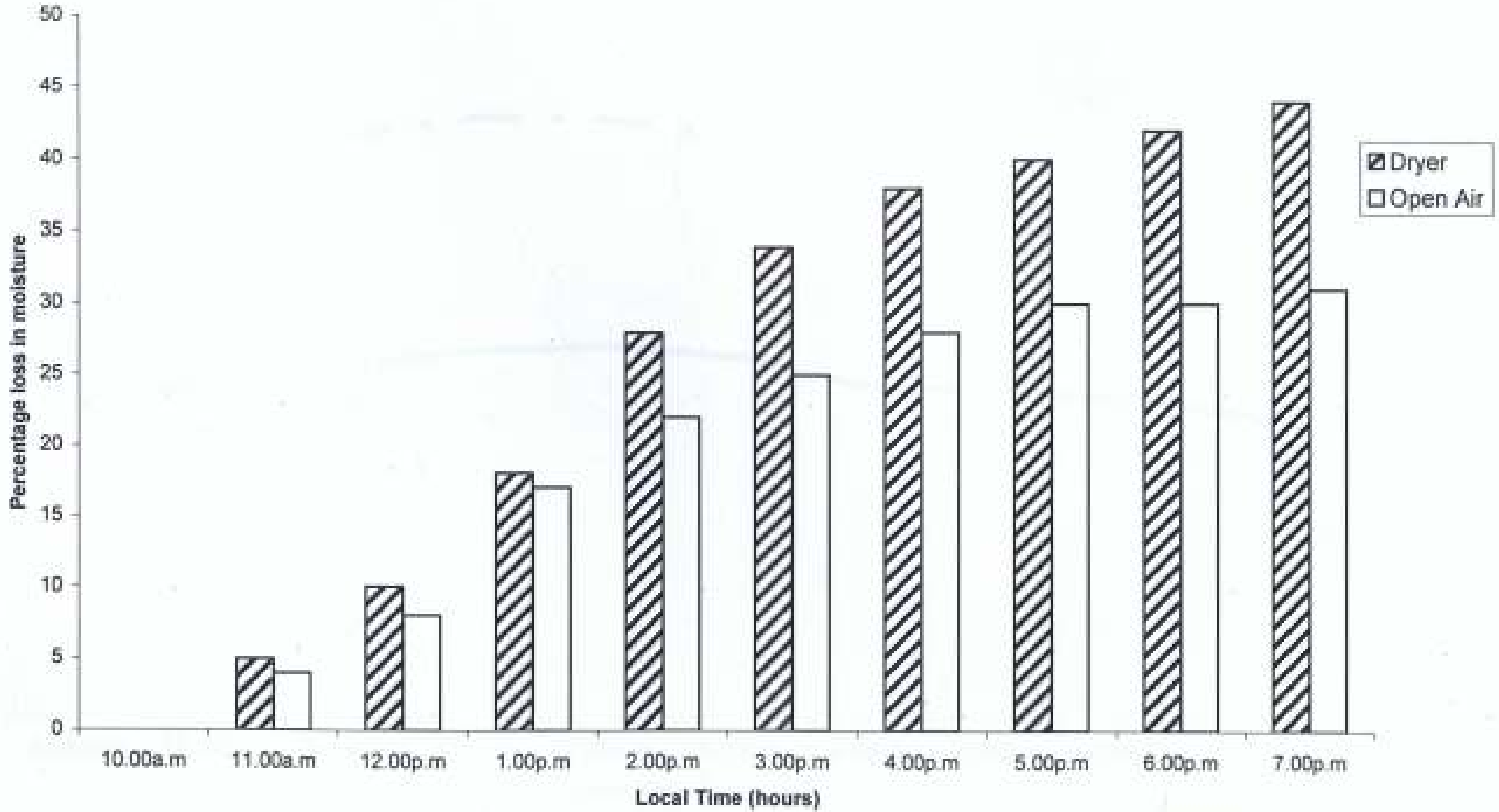


Fig.4.6: A bar chart showing percentage loss in moisture of sample I 24/02/2004

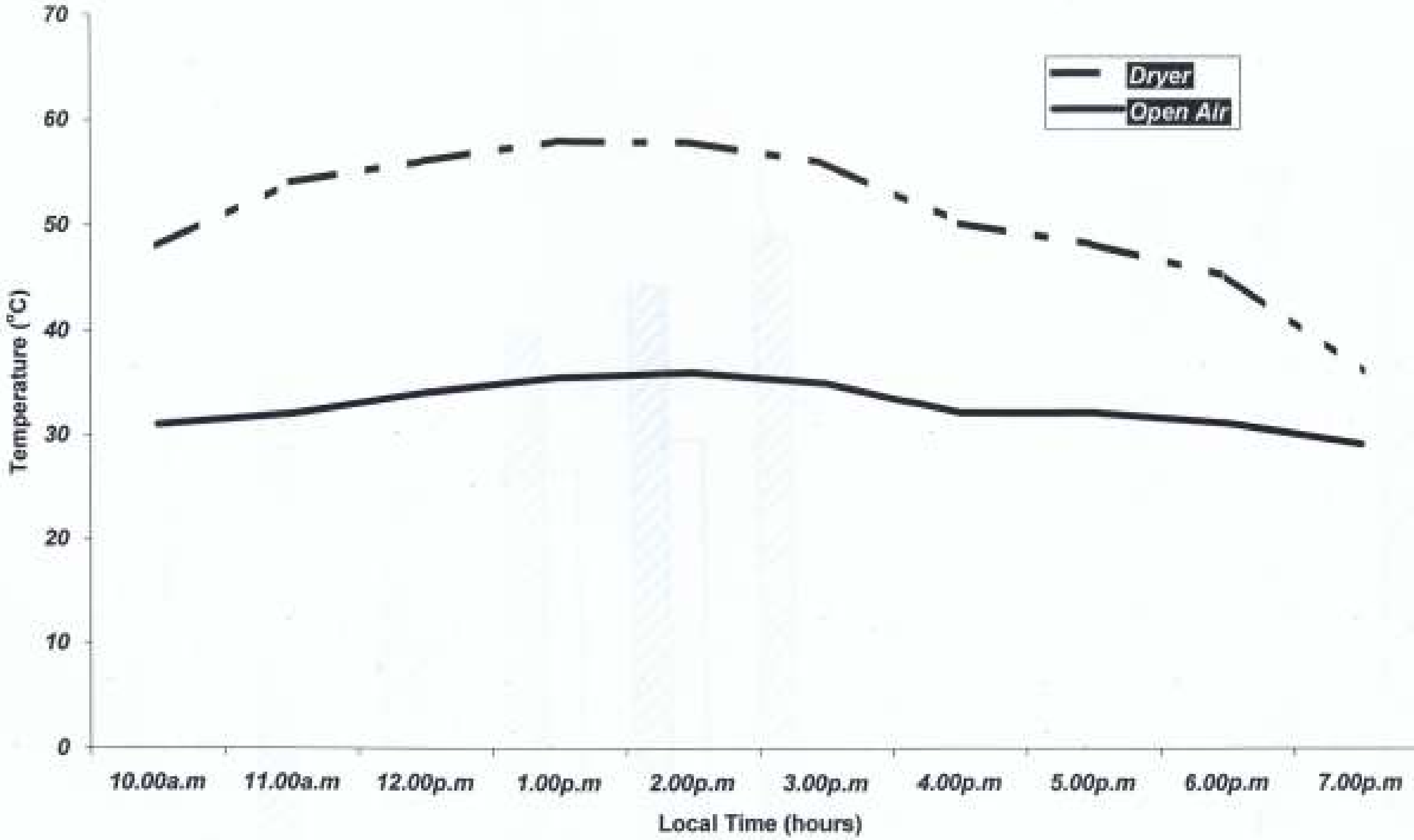


Fig.4.7: A plot of temperature against time for sample I 25/02/2004

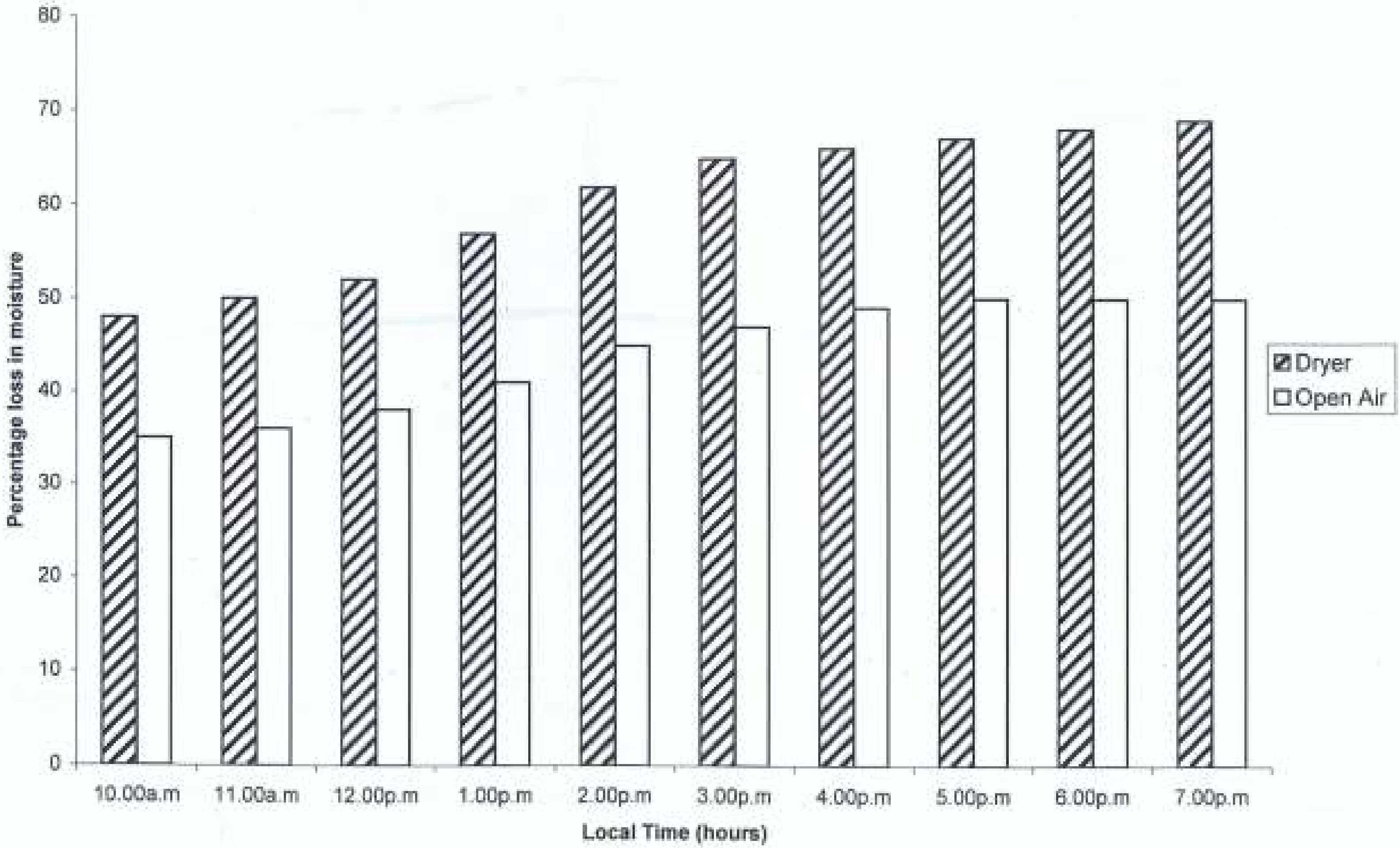


Fig.4.8: A bar chart showing percentage loss in moisture of sample I 25/02/2004

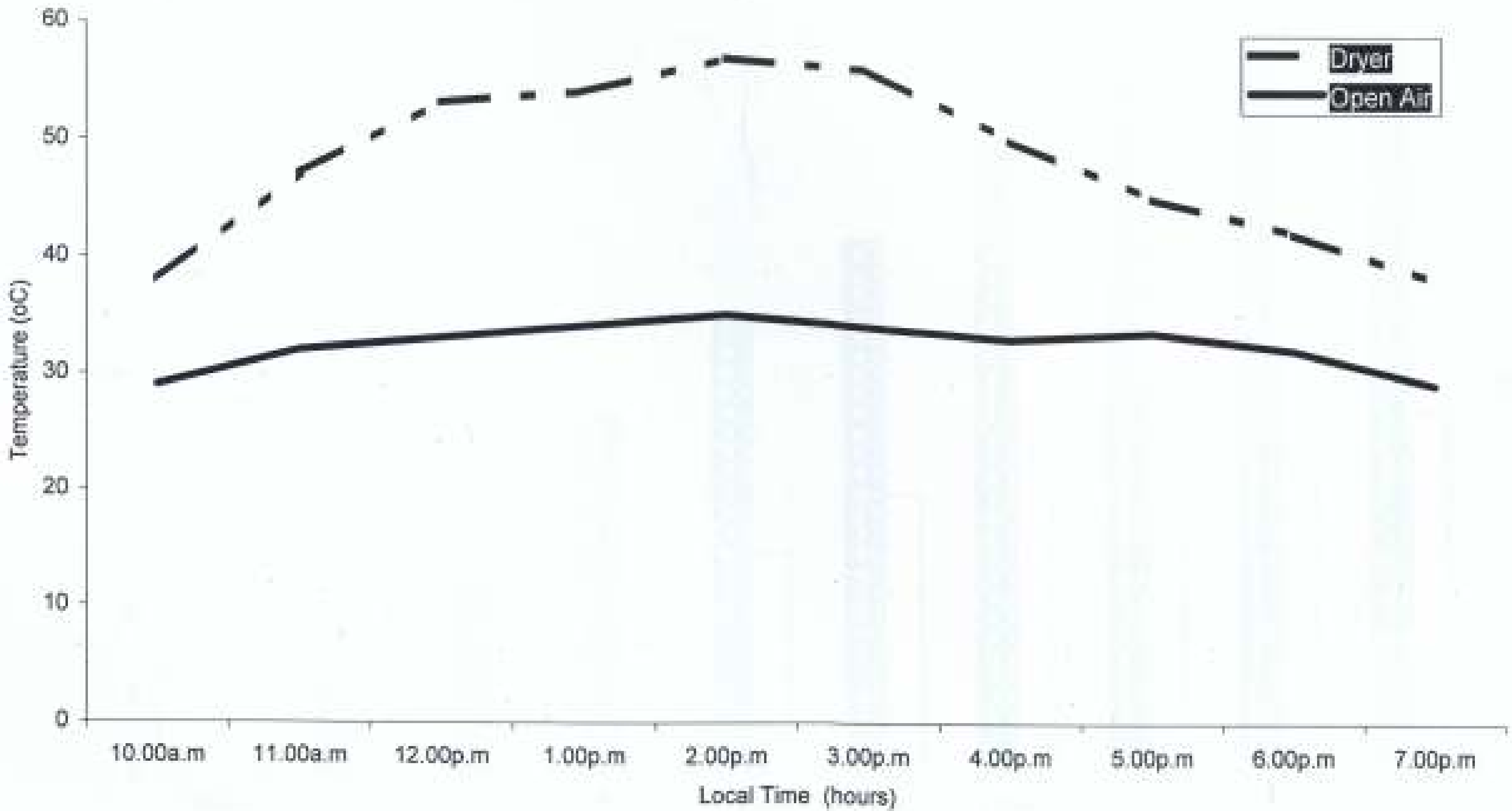


Fig.4.9: A plot of temperature against time of sample II 26/02/2004

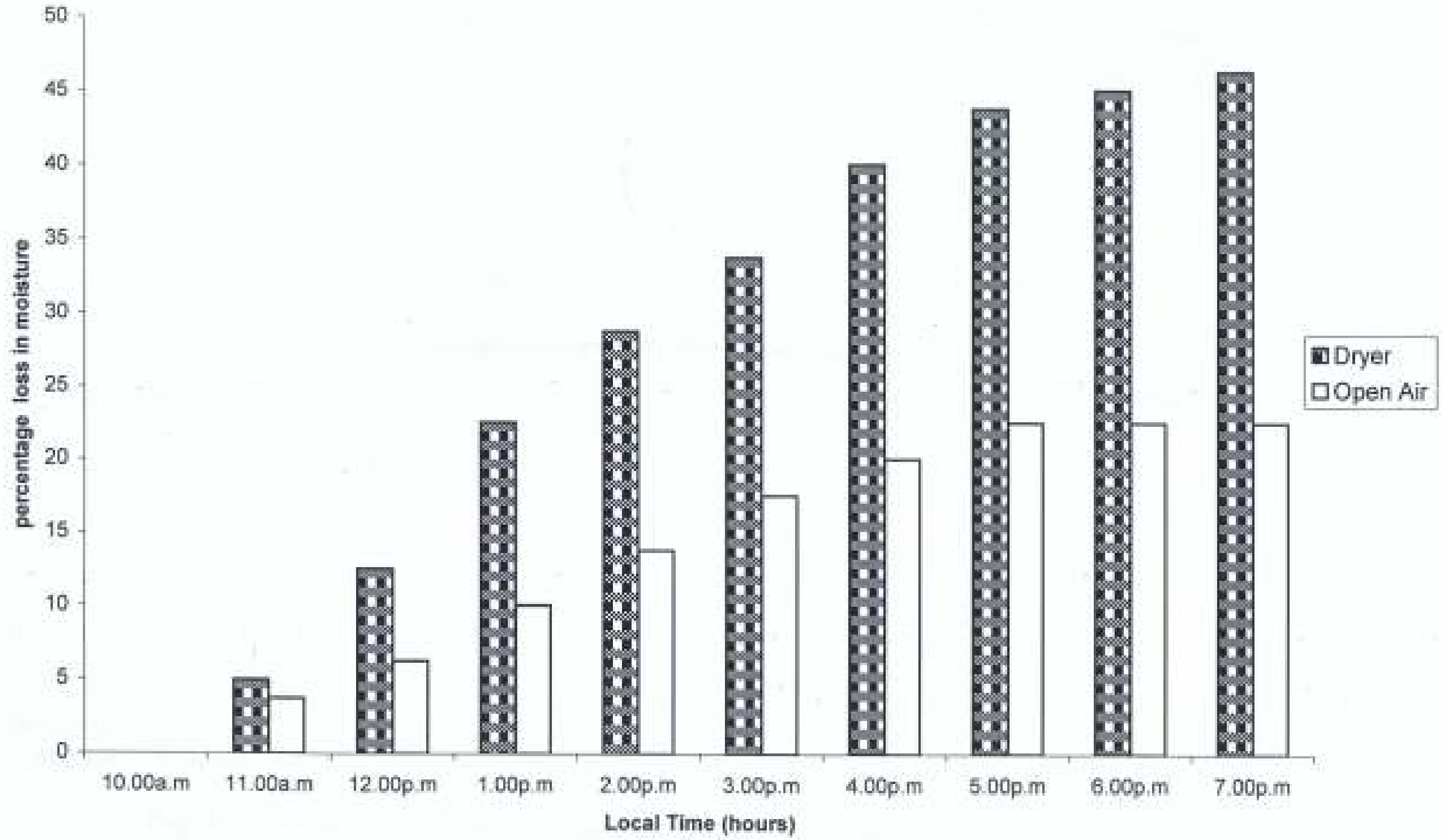


Fig. 4.10: A bar chart showing percentage loss in miosture of sample II 26/02/2004

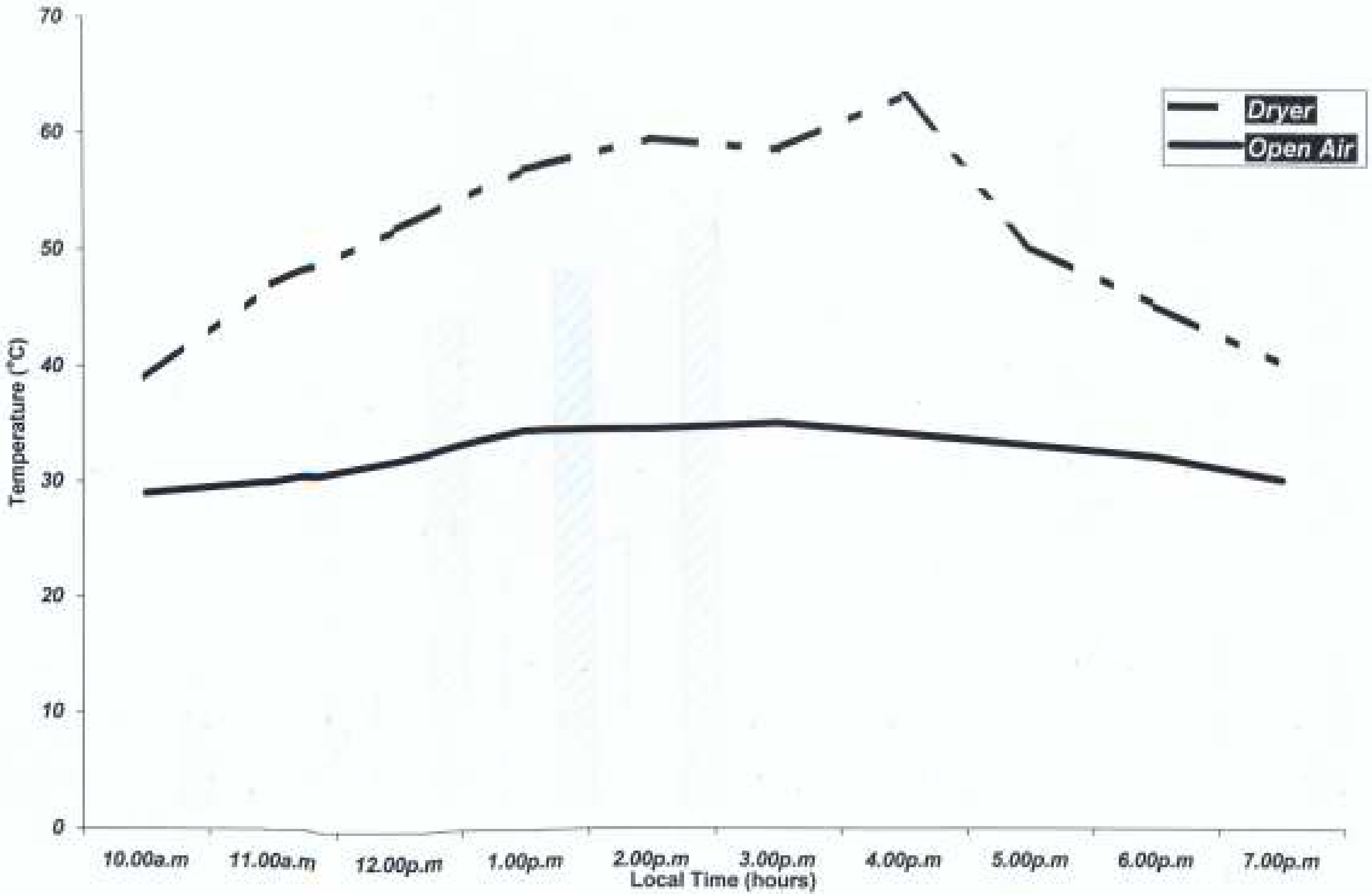


Fig. 4.11: A plot of temperature against time of sample II 27/02/2004

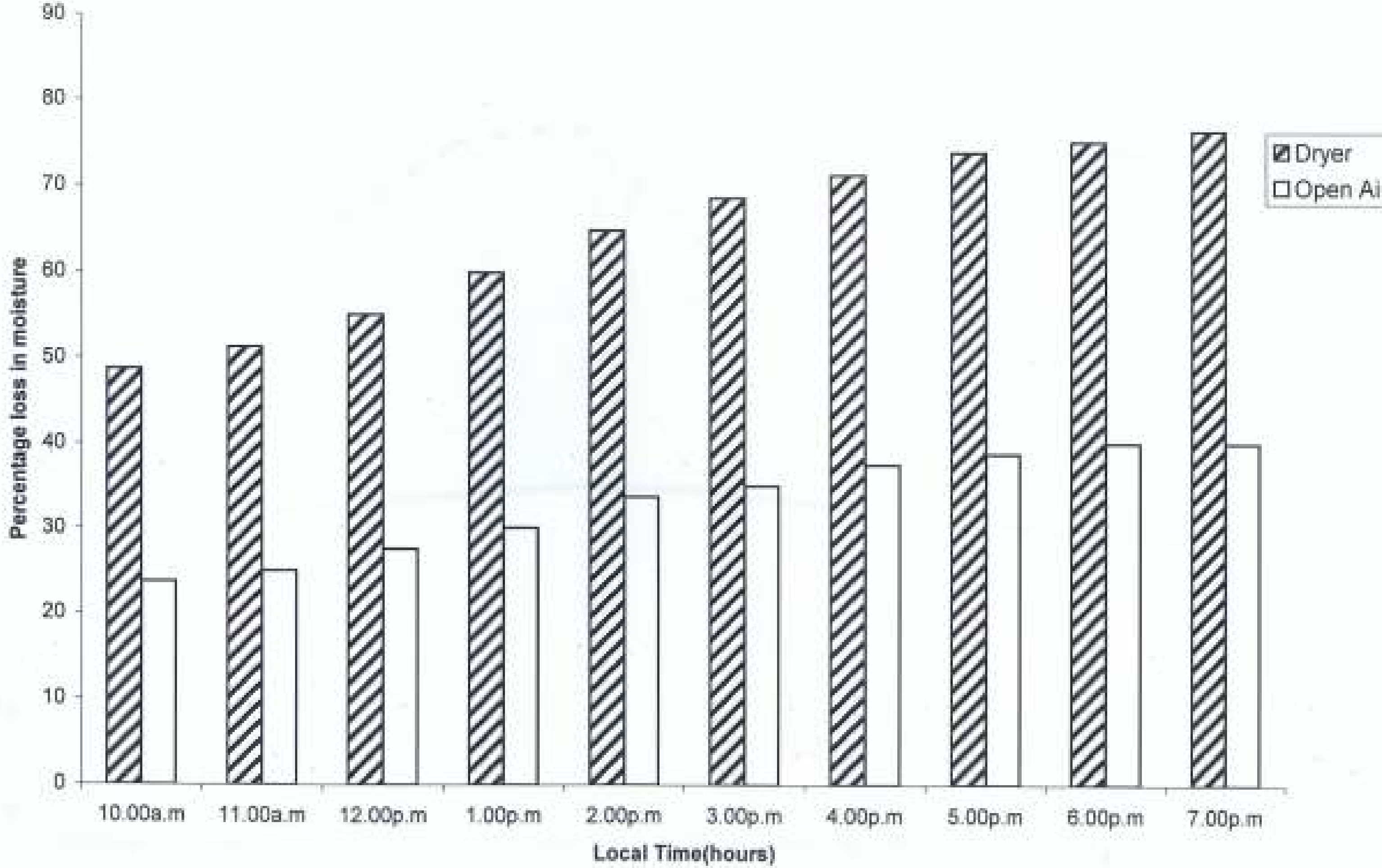


Fig.4.12: A bar chart showing percentage loss in moisture of sample II 27/02/2004

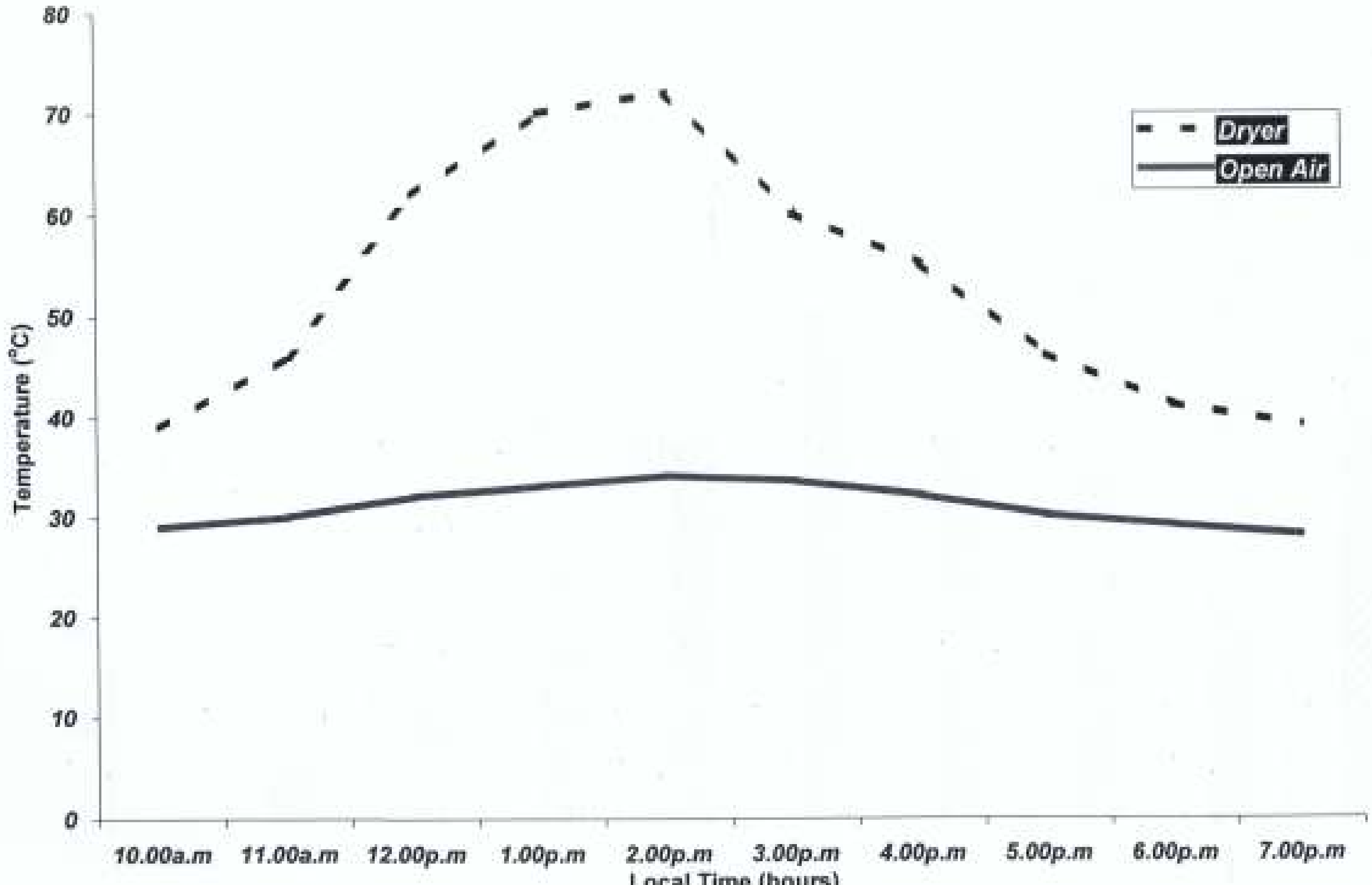


Fig. 4.13: A plot of temperature against time of sample III 28/02/2004

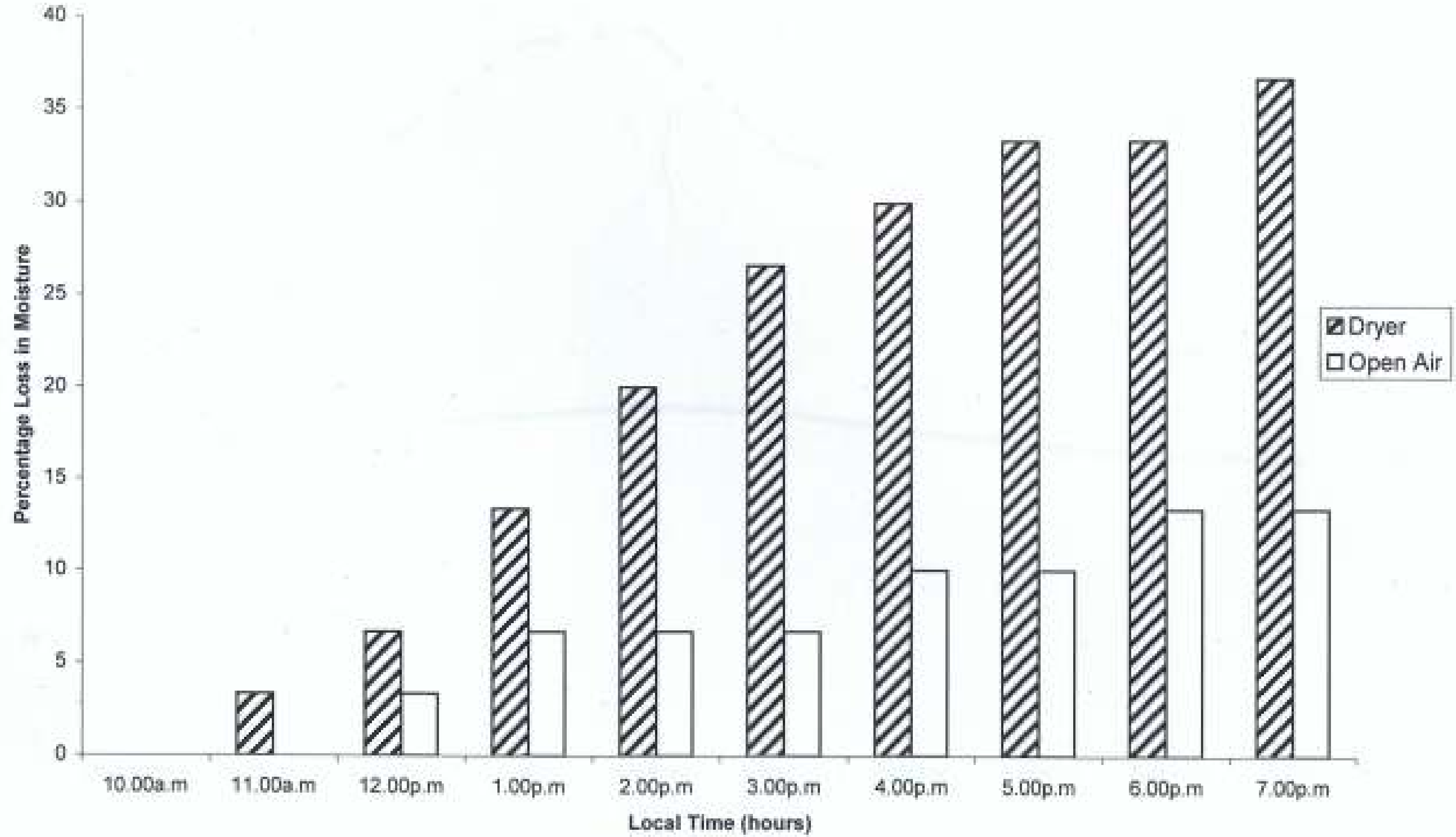


Fig. 4.14: A bar chart showing percentage loss in moisture of sample III 28/02/2004

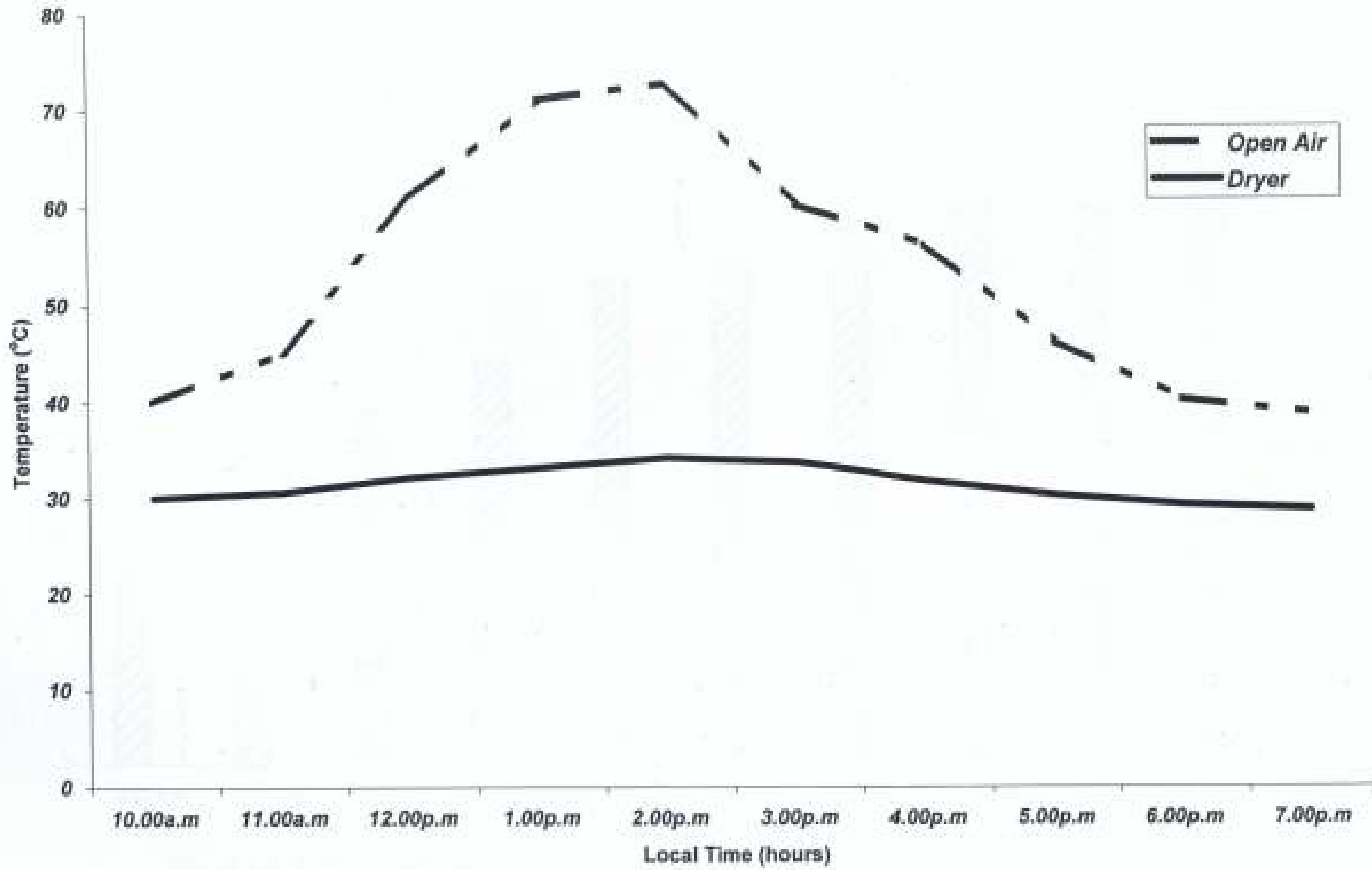


Fig.4.15 A plot of temperature against time of sample III 29/02/2004

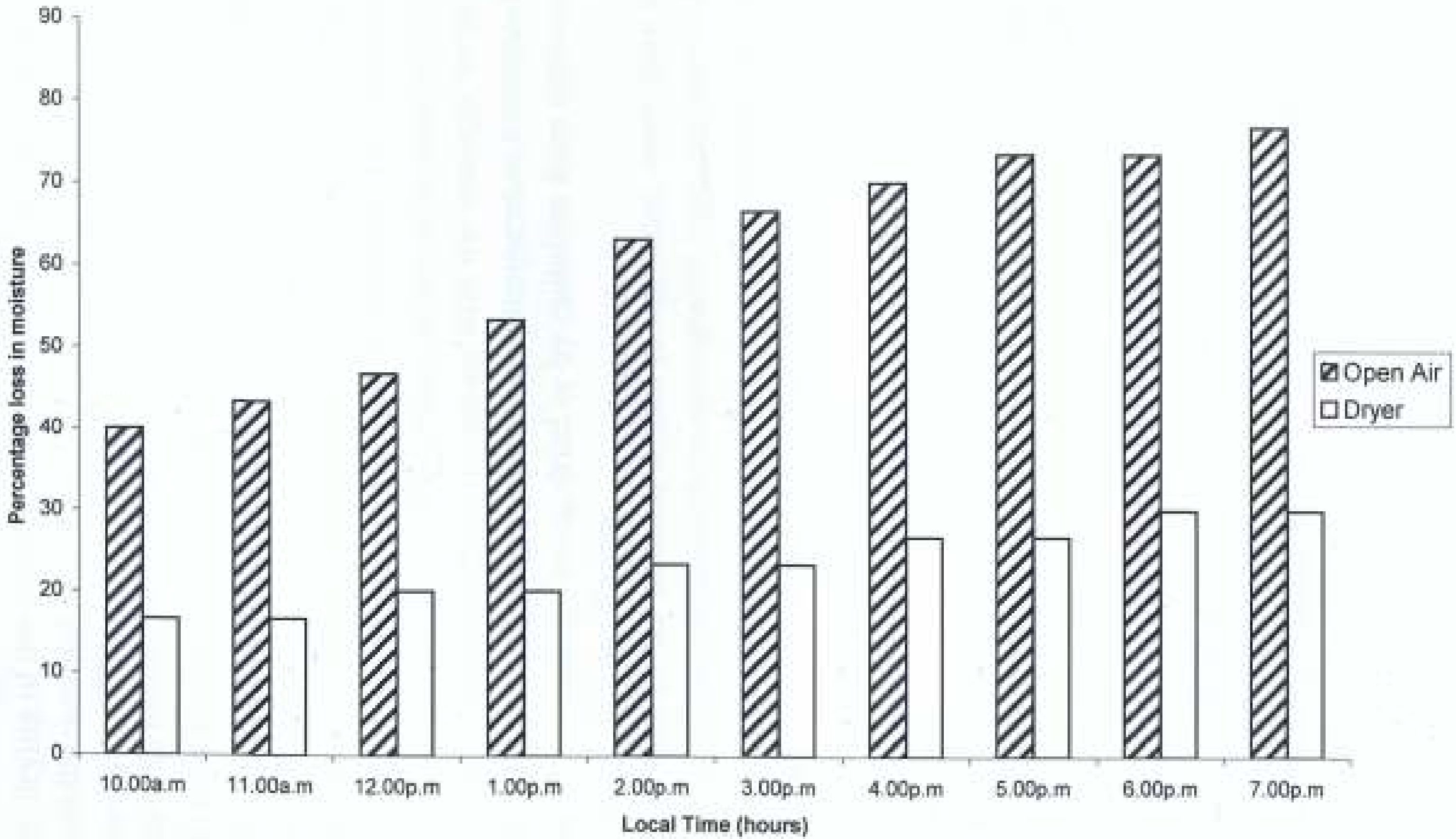


Fig. 4.16: A bar chart showing percentage loss in moisture of sample III 29/02/2004

4.2 PRINCIPLE OF DRYING PROCESS

There are three principal aspects of the crop drying process.

They are :-

(1) Solar heating of the working fluid which in this case is air.

(2) The drying of the chamber wherein the heard air extracts moisture from the material to be dried

(3) The drying of the material in the dryer.

The solar heating function consists of:

(A) Solar air heater collector using natural convention to preheat the ambient air and reduce its relative/humidity The higher the temperature the low the humidity. However there are some dryer that used forced or mechanical convention to preheat the ambient air for the dryer.

(B) The heated air directly dehydrates the produce. The first requirement is to transfer the heat to the surface of the moist material by conduction from heated surfaces in contact with the material, or by conduction and convention from adjacent air at temperature substantially above that of the material being dried or by radiation from surrounding hot surfaces or from the sun.

Absorption of heat by the material is used to vapourise water from it. Water starts to vapourise from the surface of the moist material when the absorbed energy has increased the temperature enough for the water vapour pressure to exceed the partial pressure of the water in the surrounding air. Steady state is achieved when the heat required for vapourisation becomes equal to the rate of heat absorption from the surroundings.

To replenish the moisture that is removed from the surface, diffusion of water from the centre to the surface of the drying material must take place. The rate of this process depends upon the nature of the material being dried and upon its moisture content at any time. It may thus be rate-limiting in the drying operation or if moisture diffusion is rapid the rate of heat absorption on the surface or the rate of vapourisation may be rate-limiting.

When direct radiation is received by the material, part of the radiation may penetrate the material and be absorbed within the solid itself. Under such conditions heat is generated inside the material as well as at the surface, and thermal transfer in the solid is accelerated.

Maximum drying rates are usually desired for economic reasons as this would give good quality product. But excessive temperature must be avoided in many materials because some materials seedlings or embryo might be destroyed.

It should be noted that due to surface drying, materials which have a tendency to form hard, dry and relatively impervious to liquid and vapour transfer must be dried at a rate sufficiently low to avoid this crust formation. Close control of heat transfer and vapourisation rates, either by limiting the heat supply or by surrounding air must be provided. This is achieved through the upper and the lower vents. The lower vent allows cool air in while the upper vent serves as an exit for the warm and moist air.

This type of drying process by allowing relatively dry air to circulate around a solid without the use of any direct or indirect heat source is known as adiabatic drying. The heat required for vapourising the moisture is supplied by the air to the solid material, thereby reducing the temperature of the air while increasing its humidity. Large volumes of air at reasonably low relative humidity must be used in this type of drying process due to low heat capacity of air. The exit air (air leaving the dryer) is nearly saturated.

Materials which contain salts and sugars e.g. fruits make vapour pressure to drop. The surface temperatures of thses materials must therefore be higher than the dry air in order for vapourisation to take place.

This implies that the adiabatic drying of these solids requires air at lower relative humidities than do materials having no solutes in the aqueous phase.

Another important property of solids which must be taking into consideration is their radiation absorption. Most solids have relative high absorptances which may change as drying proceeds. The surface of the materials becoming less or more black during drying process. Also there may be changes in opacity of the surface of the materials which are partially transparent to some of the wavelength in the spectrum of the radiant source.

Furthermore, thermal conductivity of the material is also an important property, particularly if the solids are dried in a layer of sufficient depth to require conduction of heat from particle to particle. If the thermal conductivity is poor, circulation of heated air through and between the particles of a moist solid would permit better heat transfer than direct radiation on the surface of a relatively deep bed of particles.

As the temperature of the dryer is getting lower in the evening, the stored heat in the thermal storage chamber is passed into the dryer to keep the dryer warm at a temperature higher than the ambient temperature all the time.

With these the dryer keep on drying anything place in the dryer in the evening with the help of the solar thermal energy storage device that store heat in the afternoon and release it to the dryer in the evening.

4.3 DETERMINATION OF HEAT RADIATED BY THE DRYER

In determining the energy radiated by the dryer, one have to use the blackbody principle.

A blackbody is perfect absorber and a perfect emitter. This is true of radiation for all wavelengths and for all angles of incidence. Hence, the blackbody is a perfect absorber of incident radiation. Therefore, it serves as a standard with which real absorbers can be compared.

Also, a blackbody emits the maximum radiant energy and hence serves as a standard of comparison for a body emitting radiation. The radiative properties of an ideal blackbody have been well established by quantum theory and have been verified by experiment (Robert and John, 1981)

The spectral distribution (variation of intensity with wavelength) of radiation emitted by a blackbody depends upon the temperature of the surface. The rate energy emission per unit of surface area in the wavelength band $\lambda = 0, \lambda + \delta\lambda$ is called the monochromatic emissive power, E . Its variation with surface temperature, T and wavelength λ is given by planck's distribution law

$$E_{\lambda} = \left(\frac{a}{\lambda^{5}[\text{Exp}(a/b) - 1]} \right) \text{W/m}^{3} \quad \text{.................................. (4.1)}$$

Where $a = 2hC^{2} = 3.74 \times 10^{-15}\ \text{Wm}^{2}$

$b = hc/k = 1.43a \times 10^{-12}\ \text{mk}$

h= Planck's constant 6.626×10^{-34} Js

c = Speed of light = 2.998×10^{8} m/s

k = Boltzmann's constant = 1.38×10^{-23} J/k

The total rate of energy emission per unit of surface area E is called the total emissive power and is obtained by integrating Equation (4.1) over the whole spectrum of wavelengths, i.e.

$E = \int E_\lambda \, d\lambda$ w/m^2

Substituting Equation (4.1) for E and Integrating we obtain the classical Stefan-Boltzman law.

$E = \sigma_S T^4$ ....(4.2)

Where σ_S is the Stefan Boltzman constant equal to 5.670×10^{-8} W/m^{2}k^4

Therefore the energy radiated outward by a body is obtained by multiplying equation (4.2) by the area of the dryer. Therefore Equation (4.2) becomes.

$E = A\sigma_S T^4$ ....(4.3)

Where A is the area of the body concerned

Furthermore, the net rate of heat loss by the dryer at a give temperature and a time is given by

$E = A\sigma_S (T_d^4 - T_a^4)$ ....(4.4)

Where T_d = Temperature of the dryer

T_a = Ambient temperature at the given time

With these, the highest temperature of the dryer is 76.0°C at 2p.m (Table 3.1 A).

Therefore, we can deduce the following,

Maximum Energy of the dryer is $E = A\sigma_S T^4$ from equation (4.3)

Where A = area of the dryer (receiver) excluding the glass cover since it is not part of the radiating surface.

From equation (4.3),

$A = 2.36\text{m}^2$

$\sigma_S = 5.670 \times 10^{-8}$ w/m^{2}k^4

$T = 76.0°C = 76 + 273 = 349$ K

$\therefore E = 2.36 \times 5.670 \times 10^{-8} \times (349)^4$

$= 1985.17J = 1.985\ kJ$ = Maximum energy radiated

For the heat loss at a given time we have

$E_{loss} = AC_S(T_d^4 - T_a^4)$ from equation (4.4)

$A = 2.36m^2$

$C_S = 5.670 X 10^{-8}$

$T_d = 76.0^oC + 76 + 273 = 349\ K$

$T_a = 34.0^oC = 34 + 273 = 307\ K$

$E_{loss} = 2.36 X 5.670 X 10^{-8}((349)^4-(307)^4)$

$= 1.33 X 10^{-7}(1.48 X 10^8 - 8.88 X 10^9)$

$= 1.33 X 10^{-7} X 5.29 X 10^9$

$= 787.36\ J = 0.787\ kJ$

From these, it can be deduced that the heat radiated by the dryer (efficiency of the dryer) is proportional to the radiating area and the fourth power of the temperature and nature of the radiating surface at a given time.

i.e. $E \alpha AT^4$

$E = \sigma_S AT^4$

Where σ_S is the Stefan-Boltzman constant which is of the value $5.670 X 10^{-8} W/m^2k^4$

4.4 ECONOMIC ANALYSIS

Cost analysis of the material used to construct the dryer was calculated and estimated. The dryer was constructed using inexpensive locally available materials and labour. All materials were purchased at Akure township in Ondo State, South West Nigeria. The dryer was built using welding and capentry skill.

Table 4.6 The construction costs for the dryer

ITEM	DESCRIPTION OF MATERIALS	QTY	UNIT PRICE N K	TOTAL N K
1.	Glass with dimension 69cm x 100 cm	2	2000.00	4000.00
2.	Glass with dimension 45cm x 45cm	2	1000.00	2000.00
3.	Aluminium Flat plate sheet with dimension 120 cm x 240 cm with thickness 0.9 mm	1	3000.00	3000.00
4.	$^1/_8$ inch plywood sheet with dimension 120 cm x 240 cm	1	1200.00	1200.00
5.	Foam with 1 cm thickness and dimension 120cm x 240	1	600.00	600.00
6.	Pipe (PVC) 60 cm long	1	500.00	500.00
7.	2 ft x 12 ft wood (Black Afara)	6	250.00	1500.00
8.	Tie Rod wood	6	180.00	1080.00
9.	Gallon of Black paint	1	500.00	500.00
10.	5 kg $1^1/_2$ inches nail	1	200.00	200.00
11	5 kg $^1/_2$ inch nail	1	120.00	120.00
12	Gallon of Evo-Stick gum	2	400.00	800.00
13	Tin of Glue	1	200.00	200.00
14.	Hinges & Lock	14	50.00	700.00
15.	Metal Handle	4	100.00	400.00
16.	Wire net with dimension 69 cm x 100 cm	1	1200.00	1200.00
17.	Wire guaze with dimension 69 cm x 100 cm	1	1500.00	1500.00
18.	Pebbles painted black	20	–	–
19.	PVC lock	2	200.00	200.00
20.	Workmanship (Capentry)	-	1500.00	1500.00
21.	Workmanship (Fabrication)	-	2000.00	2000.00
22	Transportation	-	1500.00	1500.00
	TOTAL			**24900.00**

Total Cost = N24900.00 (US $ 177.85)

Table 4.6, reflects the cost analysis required to construct a solar cabinet dryer with storage facilities using granite pebbles. The table shows the average price which a farmer can use to construct a medium scale passive solar dryer the farmer having all the necessary equipment can construct the dryer himself. This would give a further reduction in the cost of production

The dryer can serve a medium scale farmer without or less maintenance cost. It has no environmental hazard and no fuel cost. The availability of such dryer will enable more preservation of agricultural products and is of great value to the local farmer or users especially where there are no electricity.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 CONCLUSION

The dryer constructed in this project is a passive solar system. A passive device used natural convection of air to transmit the trapped heat, hence no mechanical system was involved. It is this trapped heat energy that dried the various sample that was dried.

In comparing the two systems, that is the dryer and the open air, it has been shown vividly that the dryer attained a temperature of $76^{\circ}C$ as against ambient which was $36^{\circ}C$. The graphs and the bar charts show this.

During the drying period, the drying inside the dryer was faster and hygenic more than the open air. The graphs and bar chart also show this.

For sample I (Plantain chips) the percentage loss in moisture in the dryer and open air are 44% and 31% respectively. This rose to 69% and 50% respectively on the second day. For sample II (Pepper) the percentage loss in moisture in the open air and dryer were 22.50% and 46.25% respectively on the first day. This rose to 40% and 76.25% respectively on the second day. And for sample III (Fish) the percentage loss in moisture in the dryer and open air are 76.67% and 13.33% respectively in the second day. By the second day, the fish in the open air have started given foul odour and not palatable for eating. This shows a very good advantage of the dryer over ordinary open air drying

5.1 RECOMMENDATION

The results obtained are indications that solar dryer has promising future for drying materials. However, if the following points are taken into consideration and effected, the dryer would perform better:

(1) To obtain a higher temperature which amount to complete absortion and conversion of solar radiation involve the use of a good material than aluminium e.g. copper.

(2) Since large volume of air is needed for the drying, then a big storage with large storage materials is needed.

(3) A blower or fan is needed for the dryer and the storage. This is to increase the rate of air movement since air is used as the heat transfer medium. This is an improvement over the natural convection air movement that is slow.

(4) If a passive system is still to be used, then the storage system can be integrated into the dryer forming part of the bed. A better output and result would be achieved.

Despite few shortcomings of the solar dryer, it still had a very numerous and good advantage over open air drying and it should be encouraged. It is suitable for all manner of drying with relatives ease even under worst weather conditions.

Because of the passive nature of the dryer, it can be located and used in remote areas where electricity and other power sources are non-existence. It's fabrication does not require high technology. And it can be operated with ease to produce good and hygienic food well protected from rodent and pest. With these, the importance of a solar dryer cannot be overemphasised.

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