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THE USE OF SOLAR ENERGY FOR YAM PROCESSING AND PRESERVATION IN NSUKKA SOUTH EASTERN NIGERIA

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ABSTRACT
The global food crisis calls for aggressive food production campaign as well as drying and storage of some of these food items so produced.This paper illustrates how free and inexhaustible supply of solar energy was used to dry yam pellets, thereby preserving the yam in powdered form for the lean periods. The dehydrator used is a solar dryer, using air as a drying medium and requiring minimal electrical power for its operation. Yam was used for the drying experiments because of its economic value in Nigeria and other African countries. The average drying time for yam pellets was 6 hours, (between 11.00am – 5.00pm during the months of November – April) .The author succeeded in producing approximately 1kg of yam flour from a simple solar dryer daily. Construction of the Solar Energy dryer and drying of the yam pellets was carried out at Nsukka in South Eastern Nigeria. Very fine flour of various species of yam was produced. Average moisture loss was 66.5% and 53.8% respectively for the two yam specimens that was dried in the solar dryer. The solar dryer produced daily average 1kg flour daily respectively. The Solar dryer with its average capacity of drying 1kg of flour can serve a family of four persons for a single meal. Industrial production of dried yam flour can be carried out by building larger type of the solar energy dryer based on the same principle like the prototype used for this study.

Key Words: Solar Energy; Solar dryer; food production; storage, preservation.

INTRODUCTION

The one form of energy abundantly available to all nations is the power of the sun. Sun drying is the oldest and commonest method of drying agricultural products. Sun drying has many drawbacks, e.g., low quality due to over drying, contamination by dust, insect infestation and degradation by over-heating (Eze et al, 1999). The advantages of solar drying are that it is simple, cheap, maintains the quality of the agricultural products and their visibility (Adesuyi, 1991). Arinze et al (1992), also concluded that open- air field drying took about twice as much time to dry compared to artificial drying of forage crops in forced natural and solar-heated air drying system and in a protected environment produced satisfactory results. Oparaku (2008) established that a solar dryer was able to dry fish in three days while the fish in the sun drying method was infested with maggots on the second day probably because of prevailing weather conditions during the drying period. The texture and flavour of the solar dried fish was better and superior to the sun dried fish. Habou et al (2003) in a comparative study of the drying rate of tomato and pepper using forced and natural convection solar dryers established that the percentage moisture removed from tomato and pepper is 93.74% and 91.11% respectively using forced convection drying at an average solar radiation of 449.38 W/m^2, while under similar sunshine condition the percentage moisture removed from tomato is up to 96.925 using natural convection drying. The forced convection drying time is only 64.23% that required for drying under natural convection.

The rising cost of fossil fuels and their dwindling supply has made industrialized nations to realize that the prodigal waste of fuels stored from geologic times cannot continue. Sun could replace a very substantial part of the fuel which, in the foreseeable future will be urgently required for other purposes. It has been estimated that the sun shine which falls on every square meter of the Earth is a potential power source of 1.4KW, and that every 45 hours the sun supplies the Earth with as much energy as our total remaining useable reserve of coal, oil and gas (Farrington, 1964).

Apart from the use of Solar energy for providing refrigeration for preserving food, distillation plants for drinking water and irrigation, solar energy could be tapped by very simple machines for dehydrating fruits, fish vegetables and grains.

Estimates from hotels, and individual homes show that about 20-30% of the harvested food crops like yams, plantain and other foods are spoilt due to lack of good storage facilities. The supply of these food items fluctuates, being plentiful during the harvest season and lacking during the planting season, especially for yam, resulting in high relative cost if available.

In Nigeria very little has been done on Food processing and Preservation. There is still in Nigeria a period of relative abundance of food-stuff during and immediately after harvest followed later by a period of scarcity. This situation is symptomatic of the state of the nation’s agriculture – distinctively and predominantly under-developed. No nation can afford wastage during the bumper season of food supply. It has to save for the lean period through processing and preservation. Any processing method adopted must be such that available technology can support it.

NEED FOR YAM PROCESSING THROUGH DEHYDRATION OF YAM PELETS

A major contributing factor to the cost of yam is cost of transportation from the farm to the market. With dehydration of yam and other food crops using a solar dryer near the site of supply and packaging in polyethylene bags, freight would be reduced leading to lower cost. Yam meal *(fuu-fuu*) is traditionally prepared by pounding. This is laborious and time consuming. Dehydration of yam and turning it into flour would ensure the preparation of instant yam meal at no great cost or inconvenience. Yam seeds produce seed yams. Yam is prone to micro-organism attack under storage conditions. It also has the tendency to sprout. Sprouting yam is unpalatable. Hence dehydration of some yam during the harvesting season would help check the high wastage due to micro-organism attack and sprouting.

Crop dehydration is all about destroying micro-organisms responsible for food spoilage and preventing re-infection or creating conditions in and around the food so that micro-organisms cannot grow even when present. Eze et al (2008) investigated the nutritional, microbial and sensory qualities of open air and solar dried tomato and okro using a constructed solar dryer. Results showed that the tomato and okro were successfully dried at temperatures attainable within the solar dryer with minor qualitative and organoleptic losses. The moisture content, microbial load, vitamin C, and B_2 contents decreased during drying.

Due to the problems of slow drying and mouldiness that are encountered in drying plantain and cassava chips, Adesuyi (1991), investigated the use of fabricated solar dryers to dry these food crops. He established that mouldiness in cassava and plantain was highly significantly reduced in solar dryers (4 and 6%) than ambient drying (34 and 36%) respectively.

The most favorable climates for taking advantage of solar energy in food dehydration

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are found in the equatorial regions of the world. It is mainly in these regions that the need is greatest for very simple machines (e.g. the Solar Energy Dehydration Unit, - the subject of this paper) which can be operated cheaply and maintained by unskilled personnel.

Drying of foods using solar dryers would solve many of the pressing problems of the fortunate and less fortunate peoples of the Earth, since the quality of a food product dried in a solar drying equipment may be improved by keeping out dirt and also by reducing the time of heating, which might lead for example to less loss of nutritive value and to less production of materials with objectionable flavors (Stanley, 1971).

Lashsasni et al (2004), concluded from their work on Comparative Evaluation of Drying Efficiency of Solar Passive Dryers Using the Drying Rate Constant of Yellow Pepper and Okro as a case study that the drying rates of most fruits and vegetables occur in the falling rate period of drying rate curve.

THEORY OF FOOD DEHYDRATION

Dehydration as a means of preserving food will be of greater use in the near future more than other food preserving techniques. Most food-stuffs consist of proteins, fats, carbohydrates, oils, and other chemical compounds such as vitamins and minerals which are water soluble (Stanley, 1971). When the moisture content of a food substance is reduced below 10%, micro-organisms are rendered inactive. Reduction of the moisture content below 5% preserves the flavor and nutritional value. This forms the basis for the preservation of food through dehydration (Stanley, 1971). While preserving food from a microbiological standpoint, it is also necessary to preserve its flavor and nutritional characteristics as well. The delicate characteristics of food require the skillful design and fabrication of the dehydration system and this requires an understanding of the principles of dehydration (Stanley, 1971). Foodstuffs may be dried in any of the following mediums:-

(a) in air (b) in inert gases (c) in superheated steam (d) in vacuum (e) and by the direct application of heat.

Dehydration by Air

In industrial processes, air is generally used as the drying medium because it is plentiful, convenient, and overheating of the food can be controlled (Charm, 1971).

Air conveys heat to the food, causing water to vaporize, and is also the vehicle to transport the liberated moisture vapor from the dehydrating food.

No elaborate moisture recovering system is required with air as is needed with other gases. Drying can be achieved gradually, and scorching and discoloring tendencies are within control. Generally more air is required to conduct heat to the food to evaporate the water present than is needed to transport the vapor from the chamber. If the air entering is not dry, or if air leaving the dehydration chamber is not saturated with moisture vapor, the volume of air required is altered. Less humid air removes the water that evaporates from the solid material over which the air is passing faster, In as much as the heat capacity of air is low, it is necessary to use large volumes of air (Stanley, 1971).

Rate of Evaporation from Free Surface

Drying times for specific products depends on the properties of the raw material including moisture content, composition and method of preparation, size and shape of pieces to be dried (Desrosier, 1970). The greater the surface area, and the more porous the surface, the higher will be the drying rate of food. Drying rate increases as the velocity of air flow over food increases. The higher the temperature of air, and the greater the temperature drop, the faster the rate of drying will be, provided case-hardening does not develop (Desrosier, 1970). Almost as much time may be consumed in reducing the final 6%

moisture as is required to bring the moisture content from 80% to 6%. The drying time increases rapidly as the final moisture content approaches its equilibrium value (Desrosier, 1970).

Case Hardening

During drying, the velocity of air flow as well as the temperature of the air can increase while the surface area and thickness of slices remain constant. When this happens the rate of moisture removal is increased, but a dangerous situation is encountered if the rate of moisture removal near the surface is less than the rate of diffusion of moisture from the inner to the outer surface. Where this occurs, there is a high deposit of starch or sugar on and near the surface. This presents a barrier to moisture migration. Thus the outer surface is dry while the inner surface remains wet. This condition is known as "case hardening". A method of checking it is to have a measure of control over the air temperature and velocity in the drying chamber. Case hardening is avoided by using low temperature in the drying and by cutting the food items into thin slices. These thin slices dry uniformly and do not allow time for the accumulation of sugar or starch deposits before they are dry.

Percentage Moisture Loss:

The percentage moisture loss is computed on the following basis:

Water removed = Original weight minus final weight

Hence the percentage water removed is determined as:

$$\%\ \text{Water Removed} = \frac{(\text{Original Weight} - \text{Final Weight}) \times 100}{\text{Original Weight}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

Advantages of Solar Dehydration

Dehydration in a closed chamber obviously is a more expensive process than air drying, yet the dried foods may have more monetary value from dehydration in a closed chamber due to improved quality. Eze at al (1990) also discovered that the ultraviolet rays from the sun adversely affects the lycopen and darkens sun dried tomatoes after prolonged exposure to the indirect sun light, whereas the effect is lower in the case of a solar dryer.

Dehydration in a closed chamber has a lot of advantages over air drying.

(a) Dried foods from a dehydration unit can have better quality than air-dried counterparts (Eze at al, 1990).

(b) Less land is required for the drying activity.

(c) It is not susceptible to the photocatalic – oxidation of food.

(d) Sanitary conditions are controllable within a dehydration plant.

(e) Less expensive storage equipment is required for dehydrated foods.

(f) The products have prolonged shelf life.

(g) The products require less storage space as shown in **Table 5**

On the other hand,

(a) Air drying is at the mercy of the elements.

MATERIALS

THE SOLAR DRYER MODEL

The solar dryer whose characteristics are reported in this technical paper, consists of three main parts: ***the collector***, ***the diffuser*** and ***the dehydrating chamber.*** In addition to these main parts, are the inlet and outlet elbows. The system is entirely built of wood, with ***obeche*** dominating in the frame work construction.

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The unit is mounted on wooden supports which provide the various sections with the desired inclinations. The exposed surfaces are coated with oil paint to protect them from insect attack and climatic deterioration. ***Fig 5.0 shows the cross-sectional drawing of the solar dryer constructed for this project from which the technical paper was derived.***

The Collector

The flat plate collector used consists of a double walled box, open at the top. It has an internal dimension of 232.7cm x 110.7cm x 38cm and an external dimension of 244cm x 122cm x 43.5cm. The outer wall is made of 6.35cmm plywood for rigidity, while the inner wall is made of 3.17mm plywood for weight reduction. The inside is painted dull black to improve its absorptivity. The top is covered with a single layer of glass-clear P.V.C sheet. On the shorter sides, are located the inlet and outlet air ducts. Midway between the inlet and outlet ducts is the solar absorber which sits on wooden rails nailed to the longer sides of the inner wall. The absorber consists of two plain layers of aluminum gauze of mesh size 1.588mm between which there is a third layer of corrugated gauze, all painted dull black to improve the adsorptive ability and heat transfer to air.

The Diffuser

The hot air from the collector needs to be distributed evenly in the dehydrating chamber. The collector when set up is inclined to the horizontal at 10^0 while the dehydrator is horizontal. The exit from the collector measures 101cm x 101 cm x 10.5 cm while the inlet to the dehydrator chamber measures 112 cm x 38 cm. These have led to the use of a diffuser with corresponding inlet and outlet dimensions.

The diffuser is provided with separators (two of them) and they follow the contour of the top diffuser curve and deliver the air equally to the three layers of trays. The separators also serve as guides for the air, thus minimizing the loss that would have resulted from separation of the air from the sides of the diffuser because of the enlargement of the cross-section in a short distance. The diffuser is double-walled to enclose an insulating air gap.

The Dehydrating Chamber

The Dehydrating Chamber is the cabinet type and is a rectangular box measuring 122 cm x 122 cm x 48 cm. It is open at two opposite ends. One end is for the inflow of hot air from the collector while the other is connected to a 90^0 exit elbow. The inside of the dehydrator consists of two laterally symmetrical halves, left and right. Each of these contains three layers of trays made of aluminum gauze with wooden frames. Each layer contains three trays which slide on a pair of rails. There are three pairs of rails in each half. In all, the dehydrating chamber contains eighteen trays. Access to each half of the dehydrating chamber is by two doors made of 12.7 cm plywood hinged at the lower ends and provided with bolts at the upper ends.

Selection of Food to be dried

In the selection of foods to be dried much attention was paid to the changing food habits of Nigerians. In the past years emphasis has been on drying DIOSCOREA Rotundata (white yam), but it has been found that in many areas of South - South Nigeria DIOSCOREA Cayenesis (yellow yam) is used more frequently.

METHOD

Preliminary Experiments (Without food in the Drying Chamber)

In the preliminary experiments which were carried out in the month of November at Nsukka a city in South Eastern Nigeria, the trays were empty but partially covered with duplicating papers sheets, leaving uncovered an area roughly equal to that which would be left if it were loaded with specimens. This was to ensure a uniform amount of cross flow between the trays at all times.

In this case, parameters of primary interest were temperatures of various parts of the collector and drying chamber, wind velocity and relative insolation.

Temperature Measurements

Temperatures were measured at hourly intervals with a set of twenty-two thermocouples, eleven of which were located in various parts of the collector while the remainder were in the dehydrator. The thermocouples situated at the top of the system were shaded from direct rays of the sun with pieces of paper glued to positions above the thermocouple joints. For a minimum time of overlap between measurements, and for ease in measurement, all the thermocouples were passed through a pair of selector switches, eleven in each. A galvanometer and a common cold junction were used for all the thermocouples. Thus it was possible to select a particular thermocouple and record its reading with minimum delay. A galvanometer was used to indicate the potential difference across the thermocouple junctions in the form of temperature. Thus re-calibration was unnecessary. The galvanometer readings were compared with that of a mercury in glass thermometer, prior to the actual tests; and no sensible difference was observed between the readings given by both instruments.

Air Velocity Measurements

The air velocity in the drying chamber could not be measured due to non-availability of a low speed anemometer. The air velocity is the velocity of the air-flow inside the solar energy dehydrator, while the wind velocity is the velocity of the wind or air flow outside the solar energy dehydrating chamber.

The wind speed in the immediate surrounding of the Dehydrating Unit was measured with Richards Vane type anemometer.

Insolation Measurements

The relative intensity and duration of sunshine were determined qualitatively with a sunshine recorder (Made by Virtual Electronic Company, IS.7243:1974).

Secondary Experiments (Trays Loaded with Selected Foods)

The secondary experiments were with the trays loaded with selected specimens was carried out between the months of January and early April. In these tests, as in the preliminary experiments, parameters of interest are temperature, wind velocity, relative insolation, and quantity of water removed, drying time and daily output of dry product from the drying chamber.

Temperature, velocity measurements and insolation measurements were also carried out as described in section 3.2.1. Water removed was measured as a loss in weight of the originally wet specimen after it has been dried.

Thus, water removed = Original weight minus final weight. Hence the percentage water removed was determined as,

$$\%\ \text{Water removal} = \frac{(\text{Original Weight} - \text{Final Weight})}{\text{Original Weight}} \quad \ldots\ldots\ldots\ldots\ldots\ 2$$

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A specimen was first washed, and peeled, to ensure the separation of any contaminant, thereby ensuring that the surface of the specimen was not contaminated. The specimen was then sliced with a grater. The slices varied in thickness from 2 – 3 mm. Eighteen empty trays were weighed separately and later loaded with the wet slices. The trays were re-weighed to record the weight of the wet slices. A set of six loaded trays were initially placed in the drying chamber (near the outlet of the diffuser), one hour later they were pushed forward and their places taken by another set of six trays. The last batches of trays were then introduced two hours later.

Hourly readings of temperature, wind velocity, insolation and relative humidity were taken until the products were completely dried.

The trays were removed in the order in which they were put, i.e. the first 6 were removed and 1 hour later the next six were also removed. (It will be necessary to mention here that this method is not very efficient as the products were not completely dried).

In subsequent days the trays were introduced starting from the top of the drying chamber. Six trays were first placed in the uppermost layer, one hour later their positions were taken by another set of six trays and the first six trays were pushed downwards to the middle position. Two hours later the last batch of six trays were introduced at the uppermost layer and the trays in the middle layer were pushed downwards to the bottom layer. The weight of the trays and dry flakes were obtained from the weighing balance, from this the weight of dry flakes alone was obtained. The flour was obtained by pounding the flakes in a mortar. Very fine particles of the flour were obtained by sieving with 150µm and 250µm sieves.

The products were packed in polythene bags after processing.

RESULT AND DISCUSSION

The results of the experiments are shown in tables listed here.

RESULTS

Result of the Preliminary Experiments

Drying Chamber Uncovered
Without Trays (Table 1.0) and Figs 1(a) - (b).
Drying Chamber Uncovered
Trays not charged (Table 2.0) and Figs 2(a) - 2(b).

Results of the Secondary Experiments

Drying Chamber Covered
Trays Charged with DIOSCOREA Cayenesis
(Table 3.0 and Figs. 3(a) - 3(b).
Drying Chamber Covered
Trays Charged with DIOSCOREA Cayenesis (Treated with a discoloring agent)
(Table 4.0 and Figs. 4(a) - 4(b).
Tables 6 and 7 shows the result of the weight loss from the secondary experiments.

DISCUSSION OF RESULTS

Preliminary Experiments

This set of experiments was purely designed to show the characteristics of the system with respect to variations in external conditions. During the test period, a wide range of climatic conditions was encountered, with variations of wind velocity, ambient temperature and most important of all, solar intensity. As can be interpreted from the (tables 1-4 and figures 1(a) –(b) - 4(a) – (b), the temperatures of the various parts of the system increased with an increase in the insolation, peak values occurring between 1 and 2pm. Figs 1(a) - (b) show the temperature distribution within the system when the dehydrating chamber is uncovered, higher temperatures are experienced at the top of the dehydrating chamber. The very high temperature at the top could be attributed to three reasons.

(a) Hot air rises from the bottom to the top.
(b) Insolation is greater at the top of the drying chamber.
(c) The absorbing effect of the black surface of the drying chamber.

Uncovering of the dehydrating chamber is suitable when we intend to dry crops without fear of experiencing photo-oxidation, which is definitely not suitable for drying crops that have a high sugar content, because the specimens at the top of the dehydrating chamber will experience case-hardening. There were reductions in temperatures in both the collector and dehydrating chamber for the case with the drying chamber loaded with empty trays. Figs 1(c) and 2(c) show the plot of wind speed every one hour for the preliminary experiments.

Secondary Experiments

In the secondary experiments, the aim was to determine the amount of daily output of dry products that the solar drier could produce, and the percentage moisture removed, while at the same time studying the characteristics of the dryer. Average moisture loss of 66.5% and 53.8% respectively was obtained from the secondary experiments with the trays charged with DIOSCORIA CAYENENSIS. The corresponding weights of processed flour was 812gms and 1100gms respectively.

Generally, there is a variation in temperature between the various parts of the dehydrating chamber, although the temperatures of all the parts should be equal. The shapes of the curves in figures 1(a) –(b) – 4(a) – (b), in the graphs of temperatures against time, indicate higher values of temperature by the time of introduction of specimens and lower values of temperatures by the time of withdrawal of the trays from the dehydrating chamber.

Figs. (4a) - (b) indicate that the variation in temperature of the different sections of the dehydrating chamber is greatest during the periods when the trays of food were being introduced. This is due to the fact that latent heat of evaporation is taken from the hot air and transferred to the wet food specimens. Towards the end of the day, when the trays are ready to be withdrawn, all parts of the dehydrating chamber will be at an almost constant temperature. This is due to the fact that all specimens are completely dried and no more latent heat of evaporation is being taken from the hot air. This can be observed from Figs. 3(a) – (b) and (4a)- (b). The effect of wind speed (outside the Collector) on the temperatures of the collector and dehydrating chamber can be seen by observing the high value of the wind speed by 12.30pm on the Fig. 3(b) and the corresponding drop in the temperatures of the collector and the dehydrating chamber. High wind speeds cause flapping of the P.V.C. sheet resulting in heat loss from the collector. Figs 3(c) and 4(c) show the plot of wind speed every one hour for the secondary experiments.

QUALITY OF PRODUCTS

The appearance and quality of the dried products were very satisfactory. They were not inferior to commercially available products. Infact, the products will compete favorably with products from commercial firms producing yam flour.

SOURCES OF EXPERIMENTAL ERROR

(i) There may have been slight errors in the weighing of samples. This error is of the magnitude of 4gms in every 100gm or 4%.
(ii) There is bound to be moisture loss by natural convection during weighing of samples and placing on trays before placing in the dehydrating chamber. This loss is in the order of about 2.5%.
(iii) Opening of the dehydrating chamber at intervals of one hour during the introduction of the food trays may have led to some appreciable heat loss.

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(iv) In-accuracy in the reading of the thermocouples and thermometers would give an estimated error of 3%.
(v) Perfect insulation is not possible. Hence some heat should have been lost by conduction, convection and radiation.
(vi) Loss of some quantity of dry flakes during the withdrawal from the dehydrating chamber and during grinding could also introduce error. This error is in the neighborhood of 3%, i.e. 3gm in every 100gm of dry flakes.

CONCLUSION

The Solar drier has a wide range of possible applications in the drying of food-stuffs.

Average moisture loss was 66.5% and 53.8% respectively for the two yam specimens which was dried in the solar dryer, while the corresponding weight of processed flour was 812gms and 1100gms respectively. In this project, experiments were conducted with yellow yam ***(Dioscorea Cayenensis).*** The Dehydrator could also be used for drying plantain, fruits, vegetables, potatoes and even cocoa. The yam flour obtained was found generally to be edible and of good quality. The product obtained from the Solar dryer should compare favorably with yam prepared in the traditional manner and even the commercially available POUNDO yam. The system is suitable for drying in the dry season, since there are no persistent clouds. Drying was carried out between 10.30 am and 4.30pm most days and it was found that it is about the best period. Air changes outside resulted in flapping of the P.V.C. sheet covering the dehydrating chamber. The equipment can be easily fabricated by local carpenters and other artisans and is simple to operate, no technical training is required.

RECOMMENDATIONS

(1) It was discovered that very high outside wind velocities resulted in the flapping of the P.V.C. sheet consequently leading to reduction in heat transmission into the dehydrating chamber, it is recommended therefore that a means of preventing the flapping of the P.V.C. sheet be devised. If this is achievable, the efficiency of the Solar dryer will be improved for future construction.
(2) To avoid much heat loss across the diffuser, the length of the diffuser should be shortened in any future construction.
(3) Since the equipment was designed with rural farmers in mind, it is suggested that there is no need to install electrically driven fans near the inlet to the diffuser (which naturally should increase the air flow into the diffuser). However in areas where electricity is not a problem and the cost of procuring such fans can be easily met, such complexity can be introduced to increase air flow and thereby aiding the drying of the foods more efficiently.
(4) Areas of further work in this project include the following
    - increasing the efficiency of the collector.
    - Increasing the heat transmission into the dehydrator.
    - Reducing drying time and increasing the output of dry products.

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Scientia Africana, Vol. 10 (No.1), June 2011. pp 1-20
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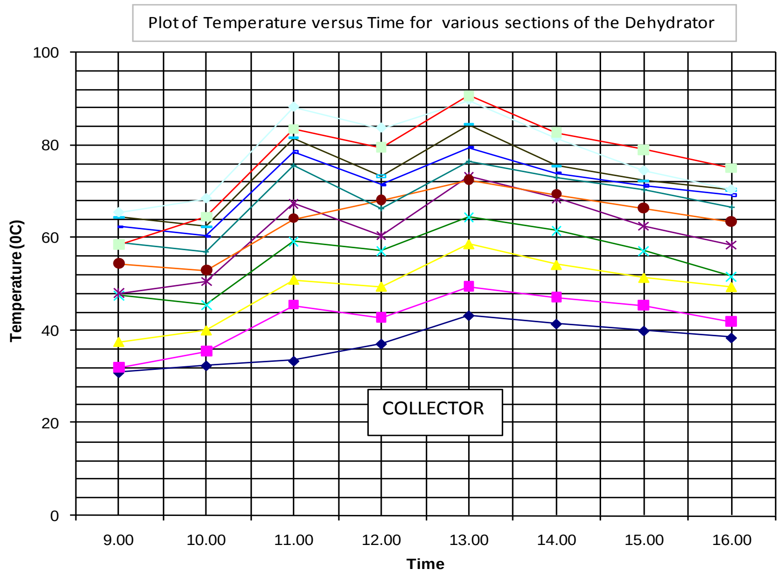
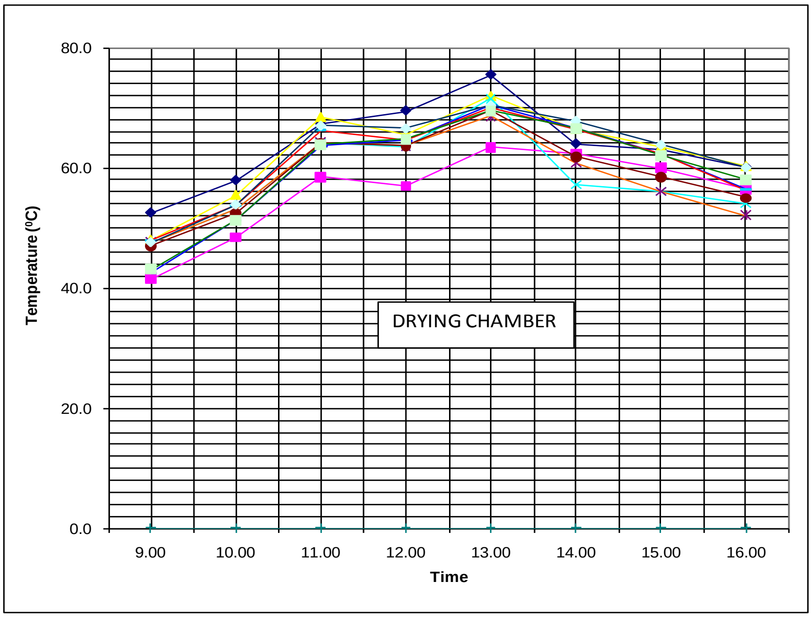
TABLE 1 DRYING CHAMBER UNCONVERTED (WITHOUT TRAYS)

Time of day	Ambient Temp (^{0}c)	**TEMPERATURE (^{0}c)**																						Wind Speed (m/min)	Weather Condition
		COLLECTOR											**DRYING CHAMBER**												
		θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}	θ_{12}	θ_{13}	θ_{14}	θ_{15}	θ_{16}	θ_{17}	θ_{18}	θ_{19}	θ_{20}	θ_{21}	θ_{22}		
9.00	30.0	31.0	32.0	37.5	47.5	48.0	54.5	59.0	62.5	64.5	65.5	58.5	52.5	41.5	48.0	47.5	47.5	47.0	-	42.5	48.0	47.5	43.0	38	CLEAR
10.00	30.0	32.5	35.5	40.0	45.5	50.5	53.0	57.0	60.5	62.5	68.5	64.5	57.9	48.4	55.5	53.2	53.2	52.5	-	51.2	53.8	53.8	51.2	10	CLEAR
11.00	31.0	33.5	45.5	51.0	59.2	67.3	64.2	75.7	78.5	81.6	88.2	83.5	67.3	58.5	68.5	64.2	64.2	64.2	-	63.7	66.2	67.0	63.8	26	CLEAR
12.00	32.0	37.2	42.8	49.5	57.2	60.5	68.2	66.5	71.5	73.4	83.7	79.5	69.5	57.0	65.4	63.6	63.6	63.6	-	64.5	64.7	66.5	64.7	76	CLOUDY
13.00	32.0	43.3	49.5	58.7	64.5	73.2	72.5	76.6	79.5	84.5	89.7	90.7	75.5	63.5	72.0	71.6	68.6	69.5	-	70.4	70.0	70.4	69.5	120	CLEAR
14.00	34.0	41.5	47.2	54.2	61.5	68.5	69.4	73.0	74.0	75.6	81.5	82.7	64.0	62.4	66.5	57.2	60.8	61.9	-	66.5	66.5	67.8	66.5	130	CLEAR
15.00	33.0	40.0	45.3	51.4	57.2	62.5	66.3	70.4	71.3	72.4	74.5	79.0	63.0	60.0	63.5	56.0	56.0	58.4	-	62.4	62.4	63.8	62.0	129	CLEAR
16.00	32.0	38.5	42.0	49.4	51.6	58.4	63.5	66.7	69.3	70.4	70.4	75.0	60.1	56.5	60.3	54.0	52.0	55.0	-	56.4	56.4	60.0	58.0	70	CLEAR

Fig.1 (a) - (b) DRYING CHAMBER UNCOVERED (WITHOUT TRAYS)





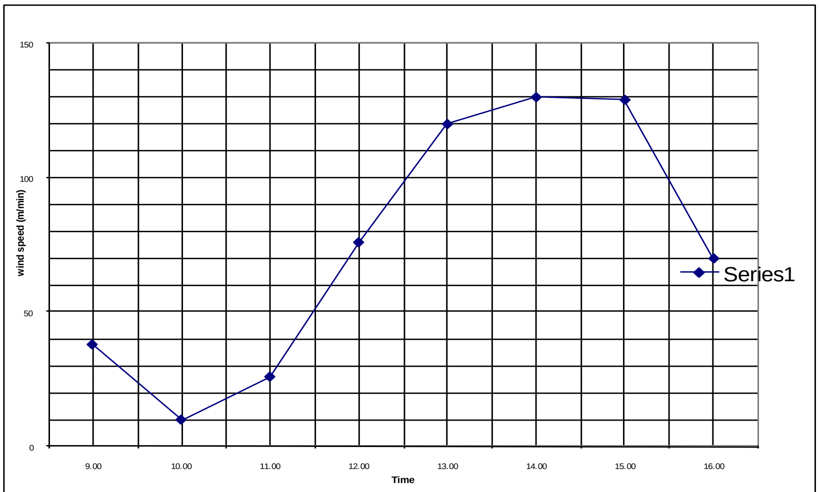


Fig. 1 (c) Plot of Windspeed versus Time

Scientia Africana, Vol. 10 (No.1), June 2011. pp 1-20

ISSN 1118 - 1931

TABLE 2 - DRYING CHAMBER UNCONVERED (TRAYS NOT CHARGED)

Time of day	Ambient Temp (^{0}c)	TEMPERATURE (^{0}c)																						Wind Speed (m/min)	Weather Condition
		COLLECTOR											DRYING CHAMBER												
		θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}	θ_{12}	θ_{13}	θ_{14}	θ_{15}	θ_{16}	θ_{17}	θ_{18}	θ_{19}	θ_{20}	θ_{21}	θ_{22}		
9.30	29.0	30.5	33.5	38.0	43.4	48.4	49.0	60.0	63.5	65.3	65.3	60.5	54.4	53.4	56.5	50.6	46.5	46.5	-	38.8	46.5	41.3	38.8	51	CLEAR
10.00	29.0	31.5	35.5	39.4	46.5	52.8	57.2	63.5	67.0	69.5	72.0	67.2	65.0	64.0	60.5	53.2	51.5	51.5	-	42.4	49.8	47.5	41.5	98	CLEAR
11.00	32.0	39.5	42.2	53.5	64.5	70.0	72.7	74.2	80.3	84.0	85.2	80.3	69.5	69.2	72.7	68.0	63.5	64.5	-	53.5	62.8	59.5	54.5	61	CLEAR
12.00	32.0	40.7	48.3	55.3	65.0	73.5	73.5	76.4	79.5	84.5	91.4	89.5	78.7	75.2	84.5	76.5	70.6	73.5	-	63.0	70.6	69.2	61.5	32	CLEAR
13.00	32.0	41.4	48.8	54.2	65.6	73.5	72.6	74.2	80.4	85.2	85.5	86.0	63.6	62.4	73.8	72.6	66.0	69.5	-	53.0	64.5	63.8	54.2	92	CLEAR
14.00	33.0	47.6	56.4	56.3	69.7	75.3	78.5	79.3	82.6	87.5	87.5	89.0	69.3	69.3	78.4	78.4	72.0	72.0	-	68.0	68.0	66.0	60.0	78	CLEAR
15.00	33.0	43.0	46.5	56.3	66.6	72.0	73.5	75.6	81.2	86.4	86.4	87.0	68.9	68.9	76.5	76.5	70.5	70.5	-	65.0	65.0	64.0	55.0	80	CLOUDY
16.00	32.0	44.0	47.0	51.5	56.0	60.0	60.1	61.5	63.0	65.0	64.5	68.0	60.0	60.0	58.5	58.5	53.5	53.5	-	55.0	56.1	51.0	50.0	56	CLOUDY

Fig. 2 (a) - (b) DRYING CHAMBER UNCONVERED (TRAYS NOT CHARGED)

Plot of temperature versus Time for various sections of the Dehydrator

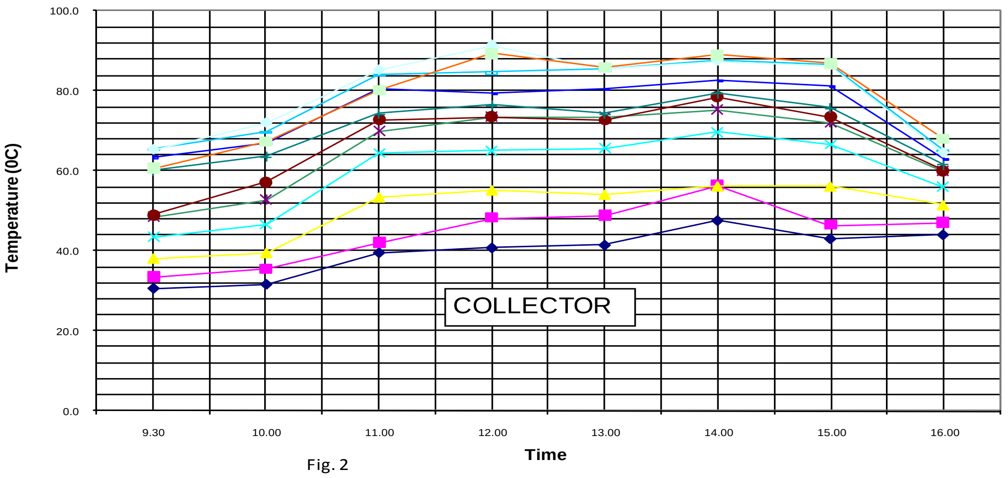


Fig. 2 (a)

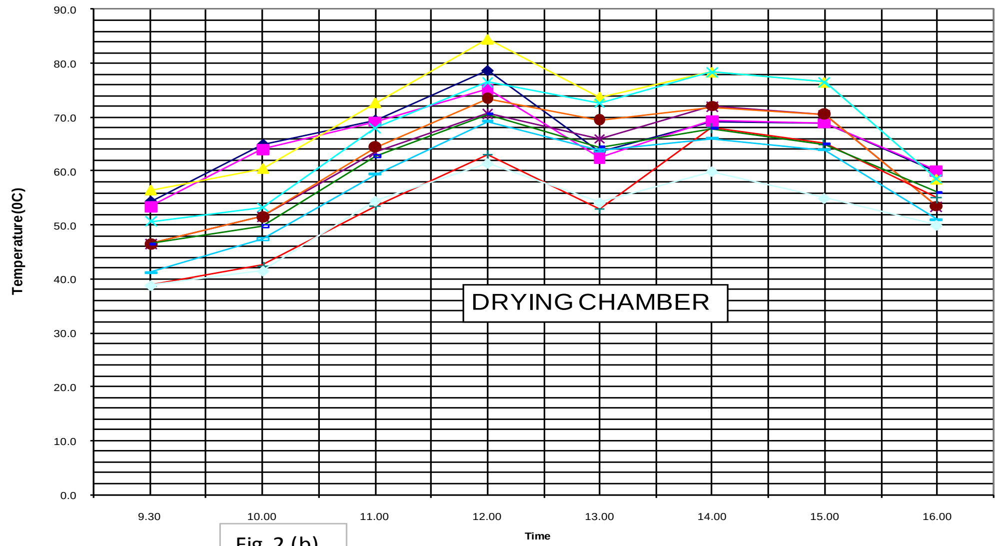


Fig. 2 (b)

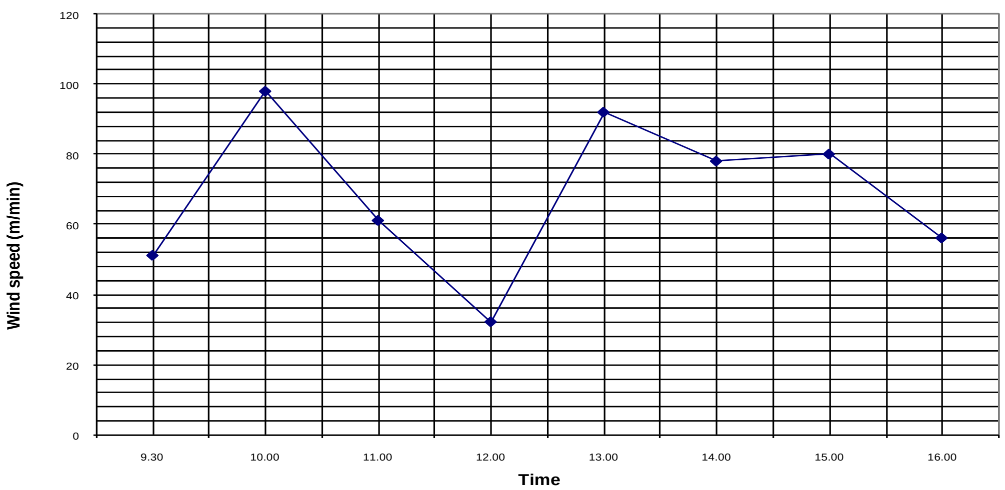


Fig. 2 (c) - Plot of windspeed vesus Time

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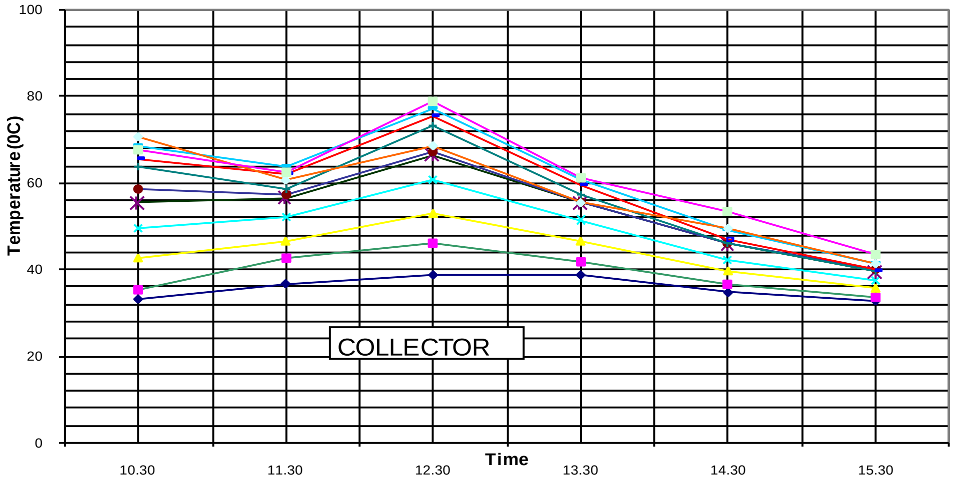
TABLE 3 - DRYING CHAMBER COVERED TRAYS (CHARGED WITH DIOSCOREA CAYENENSIS)

Time of day	Ambient Temp (^{0}c)	TEMPERATURE (^{0}C)																						Wind Speed (m/min)
		COLLECTOR											DRYING CHAMBER											
		θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}	θ_{12}	θ_{13}	θ_{14}	θ_{15}	θ_{16}	θ_{17}	θ_{18}	θ_{19}	θ_{20}	θ_{21}	θ_{22}	
10.30	30	32.9	35.2	42.4	49.3	55.2	58.5	63.4	65.5	68.4	70.5	67.5	40.3	39.4	47.5	47.5	40.3	40.3	-	36.8	40.3	40.7	37.4	95
11.30	32	36.4	42.3	46.3	52.0	56.3	57.2	58.3	62.0	63.5	60.5	62.4	39.8	38.4	47.4	45.4	36.4	36.4	-	42.0	39.4	39.7	37.4	27
12.30	32	38.4	45.7	52.7	60.5	66.3	67.0	73.0	75.4	77.0	68.4	78.6	44.4	40.3	52.7	51.3	39.4	39.4	-	33.5	40.3	40.3	35.3	185
13.30	32	38.4	41.4	46.3	51.3	55.3	55.3	57.2	59.5	60.5	55.3	61.0	41.4	39.4	45.7	45.7	39.4	37.4	-	33.0	37.4	37.4	34.4	26
14.30	32	34.4	36.4	39.4	42.3	45.7	45.7	45.8	46.8	49.0	49.4	53.3	38.9	38.4	41.4	41.4	37.4	36.4	-	33.0	36.8	36.2	34.4	92
15.30	31	32.5	33.4	35.4	37.4	39.3	39.8	39.3	39.8	41.3	41.3	43.4	34.3	34.3	36.4	35.8	33.4	32.7	-	31.0	33.4	33.4	32.0	63

FIG. 3 (a)- (b) DRYING CHAMBER COVERED (TRAYS CHARGED WITH DIOSCOREA CAYENENSIS)

Plot of Temperature versus Time for various sections of the Dehydrator



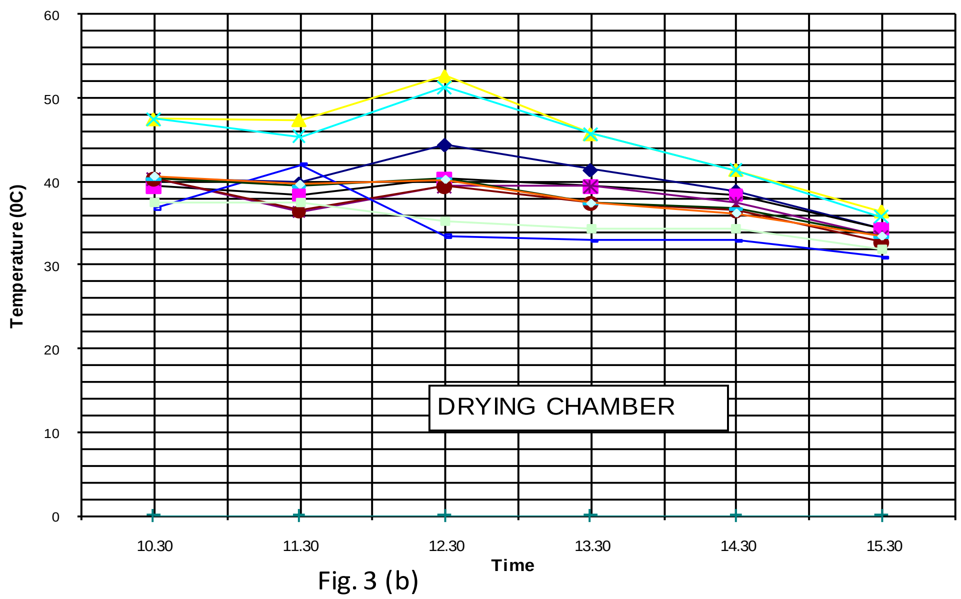


Fig. 3 (b)

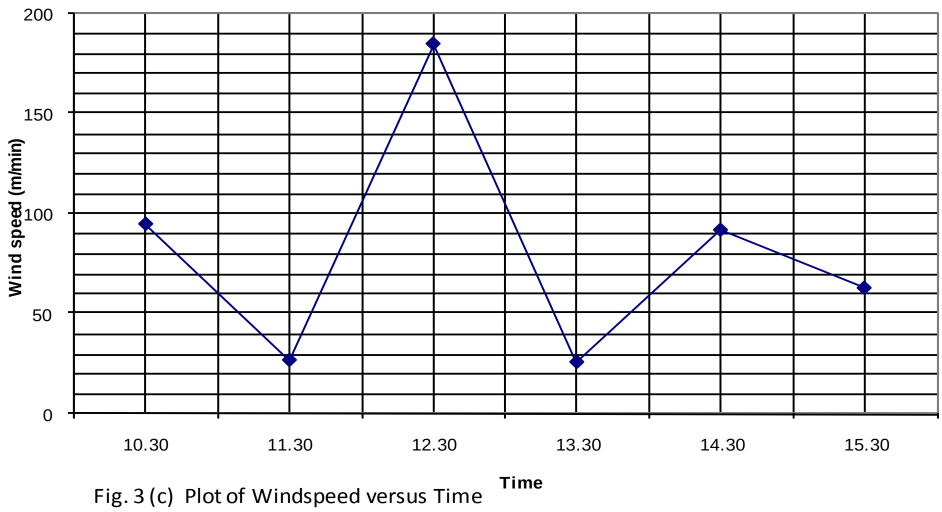


Fig. 3 (c) Plot of Windspeed versus Time

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Table 4 - DRYING CHAMBERS COVERED (TRAYS CHARGED WITH DISCOREA CAYENENSIS)

Time of day	Ambient Temp (^{0}c)	TEMPERATURE (^{0}C)																						Wind Speed (m/min)
		COLLECTOR											DRYING CHAMBER											
		θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}	θ_{12}	θ_{13}	θ_{14}	θ_{15}	θ_{16}	θ_{17}	θ_{18}	θ_{19}	θ_{20}	θ_{21}	θ_{22}	
10.30	27	33.3	37.0	40.3	45.8	50.8	53.2	58.5	60.8	60.8	58.5	53.5	32.2	32.7	38.7	34.3	33.3	33.3	34.3	34.3	29.2	29.2	27.0	100
11.30	31	40.4	43.3	48.4	55.8	60.5	65.5	68.5	71.5	71.5	73.5	70.5	41.5	38.3	45.8	41.5	36.2	36.2	34.3	34.3	36.2	36.7	31.5	162
12.30	30	39.4	45.2	50.4	58.8	64.5	65.0	67.5	70.5	71.6	68.4	66.5	40.5	37.3	45.2	40.5	34.5	33.3	32.2	32.2	35.2	35.2	30.5	117
13.30	31	41.4	47.6	57.0	66.6	70.4	72.4	78.6	74.8	76.0	72.4	70.5	42.4	39.6	47.0	47.0	36.4	36.4	34.3	34.3	35.0	35.0	33.0	50
14.30	32																							60

Drying was completed at 16.30 but hourly temperature readings could not be taken due to power failure, which started around 14.00hrs

FIG. 4 (a) - (b) DRYING CHAMBER COVERED,(TRAYS CHARGED WITH DISCOREA CAYENENSIS)

Plot of Temperature versus Time for various sections of the Dehydrator

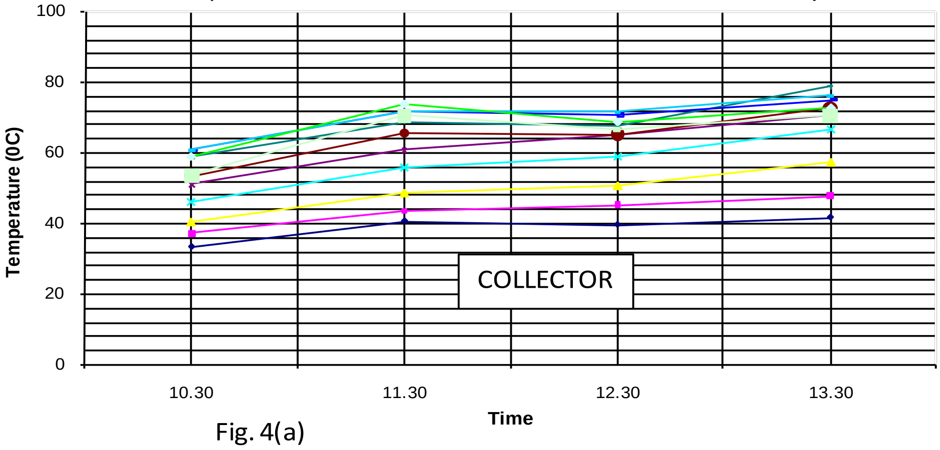

Fig. 4(a)

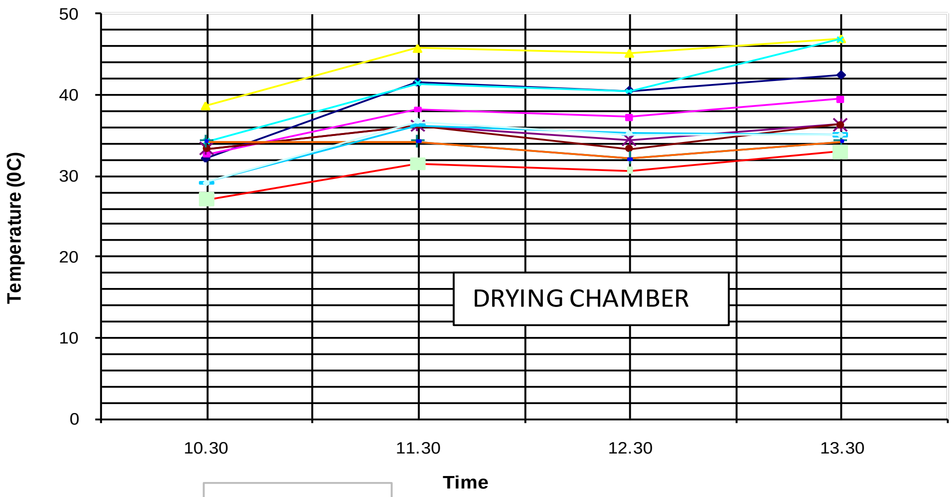

Fig. 4 (b)

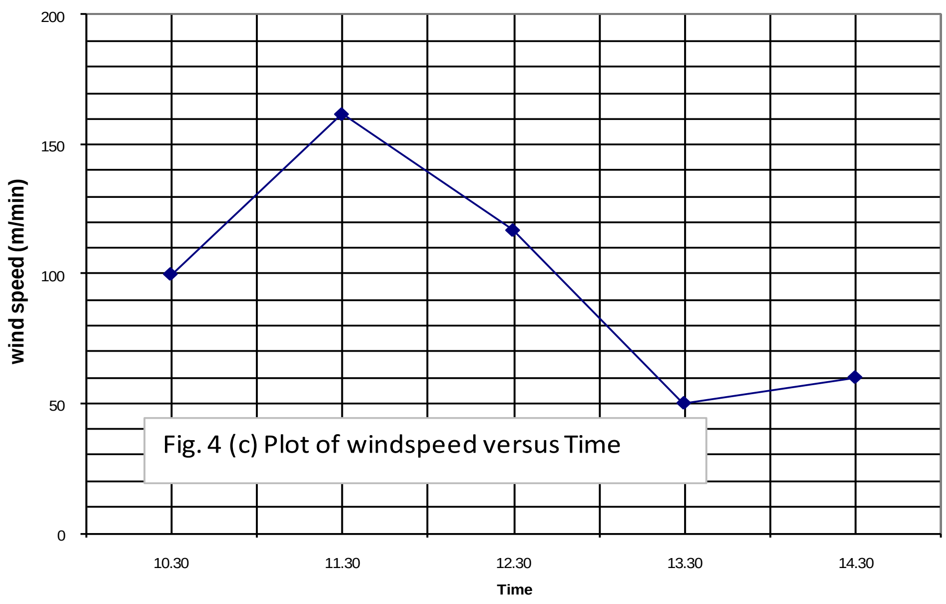

Fig. 4 (c) Plot of windspeed versus Time

Scientia Africana, Vol. 10 (No.1), June 2011. pp 1-20
 ISSN 1118 - 1931

TABLE 5

RELATIVE SPACE REQUIREMENTS PER TON OF FOOD (FRESH BASIS) (Cu. Ft. per 2,000lbs), (Desrosier, 1970)

Product	Fresh	Canned or Frozen	Dehydrated
Fruit	50 - 55	50 - 60	3 - 7
Vegetable	50 - 85	50 - 85	5 - 25
Meat	50 - 85	50 - 60	15 - 20
Eggs	85 - 90	35 - 40	10 - 15
Fish	50 - 75	30 - 75	20 - 40

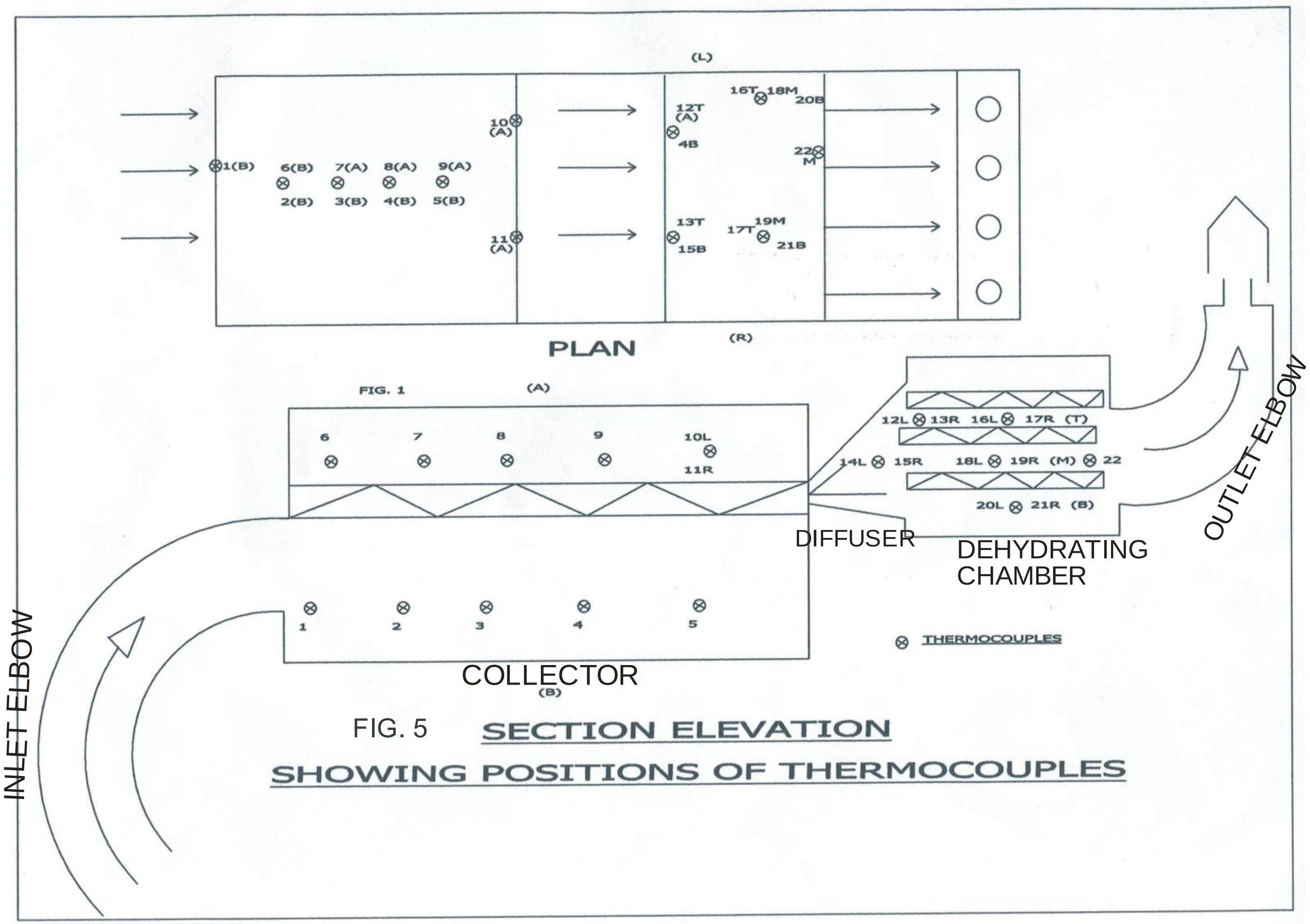

FIG. 5 SECTION ELEVATION SHOWING POSITIONS OF THERMOCOUPLES