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DESIGN AND PERFORMANCE CHARACTERISTICS OF A PALM KERNEL NUTS DRIER

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Abstract. A cabinet drier with dimensions 0.82m x 0.45m x 0.52m, having four trays and capable of drying 4kg of palm kernel nuts per hour was constructed. A control circuit to regulate the temperature of the heating chamber was installed in the appropriate parts of the drier. Using electrical heating, hot air is produced and allowed to flow through the product in order to remove the moisture. The drier was heavily lagged to conserve heat. The electronic instrumentation section of the drier has a digital display unit that allows the temperature of the drying chamber to be read. This drier was found to work satisfactorily, achieving complete drying of the nuts within the temperature range of 80°C to 100°C under 60 minutes of its operation without discolouration of the nuts or the resultant extracted oil. The maximum production requirement was 40kg per day on the basis of an 8- hour shift. The drier is also suitable for drying several agricultural products under varying temperature condition.

Keywords: control circuit, cabinet drier, agricultural products, temperature, digital display.

1. INTRODUCTION

With the increasing austere situation arising from the decrease in foreign exchange earnings by most African countries, efforts have been directed, in many countries, towards revitalizing all sectors of their economy [1]. Also with the recent devastating effect of famine on life and life pattern of some African countries, arising from drought, it is obvious that the sector that demands urgent attention is agriculture. For Africans to produce enough food to feed themselves, they must improve on their methods of food production, processing and storage.

Drying is one of the major processes involved in food preservation. In food items, two types of water are present, the chemically bound water, and the physically held. In drying, it is only the physically held water that is removed. The main reason for drying a food item is to reduce its water content to a level that the product can be safely stored for future use without the need for refrigeration, and to lessen transportation cost [4}. The use of the sun's energy for drying has been in practice for many ages. However, the old practice of simply spreading the items in the open had proved very unsatisfactory, hence the search for alternative methods. Artificial driers, like tray driers, have long been in existence because of the advantages: protection from rain and dust, protection from animals, and from pilfering by thieves. Electricity or natural fuels usually power these driers.

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The aim of this work is to construct the body of the palm kernel nuts drier, install the necessary control system to preset and regulate its temperature and also use it to remove moisture in the palm kernel nuts before using the nuts for other products.

2. LITERATURE REVIEW

The knowledge of the values of the physical and thermal properties of any product is a pre-requisite for the design of equipment for processing of the product [10].The two most important products of the palm tree are the palm oil and the palm kernel, both of which are obtained from the fruits. Palm kernel oil (PKO) is a vegetable oil that is derived from the seed, which is protected by the endocarp of palm kernel while palm oil is obtained from the pericarp of palm fruits. Palm oil and the kernel oil became important in the latter part of the 20th century as industrial oils mostly secured from West Africa. Palm kernels obtained constitute about 45-48% (by weight) of the palm fruit. On a wet basis, the kernels contain about 47-50% by weight of oil [11].

During the nut-cracking process some of the nuts are broken. There is the need to check for the ratio of whole nuts to broken nuts that results from kernel cracking because excess of broken nuts results in a rise in free fatty acid (FFA) of the extracted oil. Breakage of nuts should therefore be kept as low as possible given other processing considerations. Insufficiently dried kernel nuts have shown a much higher rate of increase in FFA, which also lowers the quality of the product [13]. Steam sterilization of the wet kernels for several minutes prior to drying was reported to reduce the rate of increase of FFA in the kernels during storage. The moisture content and the mode of storage, which can cause the moldiness of the nuts, are therefore very important factors that must be reckoned with. All these parameters can affect the yield and quality of the products.

Out of these factors, our work is directed towards the reduction of the moisture content since the problem of drying the nuts is still there and methods of drying locally have so far proved inefficient.

Thoe and Muh in reference [12] recommended that nuts must be dried to a moisture content of about 7% before packing. Drying of the nuts is normally carried out using hot air ensuring that the temperature of the air does not exceed 80^0C so that discolouration of the nuts does not occur [15].

Drying is a process wherein moisture is removed from a food product to enhance its storability, transportability, flavour or texture [6]. During this operation, the water activity of a food is lowered by removal of nearly all the water normally present through vaporization or sublimation (in the case of freeze drying). In effect, drying can be defined as the application of heat under controlled conditions to remove the majority of the water normally present in a food by evaporation.

The design and operation of dehydration equipment aims at minimizing these changes by the selection of appropriate drying conditions for different types of food. The most widely used dehydration methods involve the exposure of foods to heated air. In this type of driers, the primary mode of heat transfer is by convection [6].

Factors that control drying, different periods of drying, heat transfer and types of drier have been discussed by [6],[2], [3] and [7].

3. METHODOLOGY

3.1 *Test Equipment Fabrication*

The pictures of different parts of the drier are shown in figure 1. It is a stainless steel metal box measuring 83cm in length, 45cm in breadth and 52cm in height. 2cm square pipes were used for the framework of the drier. Sheets of stainless steel, 1mm thick, were welded onto the framework. The main body was double- walled with sawdust in-between the walls as the lagging material. Lagging is important in order to avoid heat loss by conduction. The drier has three compartments, namely: (i) the control section, (ii) the heater section and (iii) the drying chamber. The three sections have lengths 20cm, 12cm and 50cm respectively. The control compartment is thermally insulated from the heater compartment by a lagged wall in order to protect the electronic boards installed in the control section from overheating. The heater section houses the heaters and it is separated from the drying chamber by a thin perforated. A fan blows hot air from the heater through the perforations into the drying chamber.

The drying chamber was designed to accommodate four trays, which were stacked 10cm above one another by the help of four equally spaced rails welded to both sides of the vertical wall of the drying chamber. Stainless steel was used in the construction of the trays. The dimension of each tray was 50cm by 36cm and 3cm deep. The roof of the chamber has a small opening of 2cm in diameter at the top of the drying section. The opening serves two purposes: it is one of the outlets for water vapour to escape from the drier and for the thermometer used to sense the wet-bulb temperature of the chamber. The chamber has a door with hinges, which allows easy loading and unloading of the nuts.

The body of the drier was painted green, the interior, silver but the trays were unpainted because some quantity of kernel oil at the point of drying normally gets transferred from the interior of kernels to its surface. This surface oil may react with the paint to contaminate the extracted oil.

3.2 *Installation of Parts*

The electronic component boards were mounted on metal racks having wooden bases. The racks were secured to the floor of the drier by means of screws. Electrical interconnections were achieved by the use of connectors. Two 2kW heaters were installed in the heater section next to the drying chamber. An electric fan (labeled fan A) was installed with its engine in the electronic section and its blades in the heater section. The blades directly blow air around heater into the drying chamber. An "air guard" was installed over the fan to avoid air dispersal and to focus the air into the drying chamber. The velocity of the air within the drier during operation is constant at natural convection (not turbulent flow) and proportional to the power input to the fan.

The temperature sensor (i.e. thermocouple) to sense the dry-bulb temperature of the chamber was passed through a duct in the double wall and through a small hollow pipe, which has been welded to the roof of the drying chamber. The thermocouple junction projects out of the hollow cylinder into the drying chamber. When the air in the chamber is at a temperature lower than the preset temperature, the heaters switch ON and the air temperature rises. When the air temperature reaches the preset temperature, the heaters switch OFF. The heaters switch ON again when the temperature falls by about 1^0C below the preset temperature.

The control section houses the electric circuits that regulate and control the temperature of the chamber and other electrical parts of the drier.

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A second electric fan (Labeled Fan B) is installed in this compartment to blow cool air over the electronic board and the coil of fan A. The coil of fan A is not in the heater section to avoid its being overheated because the heater compartment and the drying chamber are very hot. This drier was designed to operate between 27^{0}C and 100^{0}C making it suitable for drying many food items such as maize and beans to mention a few.

3.3 Raw Material Supply and Preparation

The palm kernel seeds used in this work were obtained from a village named "Board" near Akure within the South West zone of Nigeria. Akure is on latitude 7^0 14N and longitude 5^0 08E. On receipt, the dirts and pebbles in the nuts were removed without washing because washing would introduce increased free fatty acid [FFA], which would affect the quality of the product. Care was taken to use newly cracked nuts and not old stock, which might have been partially dried. There was no need of *size reduction (*which is the process of breaking up the nuts to a small and regular size in order to aid all parts of the nuts being dried at the same rate) because it already maintained approximately small and regular shape.

4. EXPERIMENTAL SET-UP

4.1 Preliminary Experiments (With Drier Only)

After installation, the completed work was test-run at some temperatures. The temperature readings on a digital display installed in the equipment and a reference mercury-in-glass thermometer were recorded. The reading tracked each other. The maximum difference recorded was 0.5^{0}C. The following preliminary experiments were carried out to determine the characteristics of the drier.

Experiment 1: The drier was empty and the temperature of the chamber was preset to 100^{0}C. Thereafter readings of the temperature were taken at regular intervals of 1 minute. The readings taken two times are shown in columns 2 and 3 of Table 1.

Experiment 2: The chamber was heated to 100^{0}C and allowed to cool while the door was kept open. Readings of the temperature were recorded at intervals of 1 minute. This is shown in column 4 of theTable 1.

Experiment 3: The chamber was again heated to 100^{0}C. It was allowed to cool while the door was kept closed. Readings of the temperature were recorded at intervals of 1 minute (See column 5 of Table 1).

Results of The Preliminary Experiments

The graphs of the various data are shown in figure 2. It is observed from curves 2_a and 2_b that the temperature of the heating chamber increased with time until the preset temperature was attained. However, the graph of 2_a is not as linear as that of 2_b. The difference in the two graphs is due to heat absorbed by inner wall of the drier during experiment 2_a. Therefore, whenever the drier was to be used, it was first turned on for 10 minutes before the drying process actually commenced,

From curves 3 and 4, at about 100^{0}C, the cooling rate when the door was opened was three times the cooling rate when the door of the chamber was closed. In both cases the cooling rate became lower as the ambient temperature was approached.

These preliminary experiments showed that the drier is highly reliable. The drier heats up rapidly, taking a maximum of 7 minutes for its temperature to rise from ambient to 100^{0}C. Also the drier cools rapidly when the door is opened. The maximum time the drier takes to cool from 100^{0}C to 40^{0}C is 10 minutes. However, when closed it takes as long as 34 minutes, showing that heat loss is minimized.

4.2 Performance Test Of The Drier

In the course of running the experiments, a dry and wet bulb hygrometer was set up in the drying chamber to measure its relative humidity.

4.3.1 First Experiment

Four trays were each filled with 1kg of the nuts. The nuts were spread in a thin layer of about two or three nuts in depth inside the trays. In all, 4kg of the nuts was used in each experiment. The trays were then inserted into the drying chamber. The chamber was maintained at a constant temperature of 40^{0}C. At intervals of 15 minutes the trays were emptied and weighed to determine the moisture loss.

And to determine the dry mass of the nuts, a sample of the nuts of mass 1000g was loaded into the oven for three hours at a temperature of 101^{0}C to remove all the moisture. Reweighing after three hours, the dry mass was found to be 919g. The moisture content X_T of each sample was determined using the equation.

$$X_T = \frac{\text{mass of wet nuts - mass of dry nuts}}{\text{mass of dry nuts}}$$

Also the dry and wet bulb temperatures of the hygrometer were recorded and the relative humidity was deduced from the psychrometric table. The readings obtained are shown in Table 2. Finally, the temperature of the drying chamber was in turn changed to 60^{0}C, 80^{0}C and 100^{0}C and all the measurements above were repeated with new samples of the nuts.

The following precautions were taken during the experiment:

(i) The drier was turned ON for about 10 minutes before drying commenced in order to enable the drying chamber walls reached thermal steady state. This highly reduced heat loss to the surrounding wall of the chamber during drying process.

The wet bulb temperature sensor was placed close to the dry-bulb sensor (thermocouple junction) in order for both to sense the same temperature and hence give accurate readings.

Table 1: Variation of temperature with time for the preliminary experiments

Time (Mins.)	Experiment 1a Temp. (°C)	Experiment 1b Temp. (°C)	Experiment 2 Temp. (°C)	Experiment 3 Temp. (°C)
0	32.0	34.0	99.0	99.5
1	41.0	45.0	77.0	95.0
2	50.0	59.0	66.0	91.0
3	60.0	71.0	56.0	86.0
4	70.0	82.0	51.0	79.0
5	80.0	92.0	47.0	75.0
6	90.0	98.5	45.0	71.0
7	98.0	99.5	43.0	68.0
8	99.0	99.9	41.0	66.0
9			40.0	64.0
10			39.0	62.0
11				60.0
12				59.0
13				58.0
14				56.0
15				55.0
16				54.0
17				53.0
18				52.0
19				51.0
20				50.0
21				49.0
22				48.0
23				48.0
24				47.0
25				47.0
26				46.0
27				46.0
28				46.0
29				45.0
30				45.0
31				45.0
32				44.0
33				44.0
34				43.0

It should be noted that an electronic humidity sensor is better suited for this experiment. However, it was not available when this work was on.

(ii) The laboratory used was well ventilated such that warm moist air discharged from the drier did not affect the original inlet conditions over the period of the experiment.

(iii) Drying was done under constant drying condition i.e., the temperature, humidity, velocity, wet material shape and direction of flow of the hot air across the drying surface were constant. It is noteworthy that only the conditions in the airstreams are constant. The

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Table 2: The overall result for the palm kernel nuts drying experiment

Dry bulb Temp Td (°C)	40					60					80					100				
Wetbulb temp Tw (°C)	30					37					44					50				
Relative humidity (%)	40					24					14					9				
Drying time (mins)	0	15	30	45	60	0	15	30	45	60	0	15	30	45	60	0	15	30	45	60
Mass.of Wet nuts (g)	1000	992	990	989	979	1000	984	967	955	948	1000	967	955	939	924	1000	945	929	926	923
Moisture content X^1 (x100)	8.73	7.86	7.64	7.52	6.45	8.73	7.01	5.09	3.87	3.02	8.73	5.14	3.46	2.10	2.10	8.73	2.73	1.01	1.67	1.41
Percentage moisture (%)	100	90	87	86	74	100	80	59	44	35	100	50	44	25	18	100	12	12	8	5

moisture content and other factors in the solid palm kernel nuts do change however under constant drying condition [8].

4.4 Results and Discussion for The Palm Kernel Nuts Drier Experiments

The result of the drying experiment at different temperatures is shown in Table 2. It is noted that the mass of the sample decreased as moisture evaporated from either the surface or the bulk of the nuts. Figures 3 and 4 show the drying curves for the dried nuts.

In all the drying experiments, the maximum drying time adopted was 60 minutes. The curves in figures 3 and 4 show that the nuts have two stages of drying which are the constant rate and the falling rate periods. Immediately after contact between the wet nuts and the drying medium, the temperature of the nuts increases until it reaches a steady state. At steady state, the temperature at the surface of wet nuts is the wet-bulb temperature of the drying medium. At this point, the drying rate remains constant. It ends when a solid reaches the critical moisture content X_C. Beyond this point, the surface temperature rises, and the drying rate falls off rapidly. The falling-rate period sets in and it takes a far longer time than the constant rate period even though the moisture removed may be less.

The drying rate approaches zero at some equilibrium moisture content, X_E which is the lowest moisture content obtainable with the solid under the drying conditions used. However, from Figure 4, observation shows that the critical moisture content and the equilibrium moisture content exhibit dependency on temperature of the drying chamber.

For the drying chamber at 40^0C, there was no falling rate period of drying observed but prolong constant rate period. Hence, the drying process of the kernel nuts was slow and would possibly take more than 120 minutes. Similarly, at 60^0C and 80^0C, the drying period was longer than 60 minutes due to the steepness that can still be observed as the drying curves terminate at 60 minutes. However, at 100^0C, the drying period is within 60 minutes. At this point the drying rate during the falling rate period is approximately constant.

It is noteworthy that the drier will dry more effectively if (i) after loading, the drying chamber door is permanently closed for 40 to 60 minutes say, without unloading the nuts at intervals to weigh them and (ii) an electronic relative humidity sensor replaces the wet bulb thermometer. Under this condition it is found that the drier was capable of drying the nuts in less than 60 minutes at 80^0C. It is also found that at temperatures up to 100^0C no discolouration of the kernel nuts or the extracted oil was noticed.

The computed relative humidity values are shown in Table 2. According to [8], since the air entering a drier is seldom completely dry but contains some moisture and has a definite relative humidity, the portion of the water in the wet solid which cannot be removed because of the humidity of the inlet air is called the equilibrium moisture. The free moisture is the difference between the total moisture content of the solid and the equilibrium moisture content. Thus, if X_T is the total moisture content and if X_E is the equilibrium moisture content, the free moisture X is $X = X_T - X_E$. This can therefore be calculated as

$$X = \frac{\text{original mass of nuts} - \text{mass of the dry sample}}{\text{mass of the dry sample}} - X_E$$

Table 2 shows that the drier can dry the kernel nuts leaving about 5% of the original moisture (retained in the nuts) within 60 minutes when it is preset to 100^0C (approximately). This result agrees with the assertion in the Encyclopedia of Science Technology [9] that the final moisture content of dry solid is usually less than 10%.

Figure 5, which is the variation of the moisture content against relative humidity, reveals that the moisture content is directly proportional to the relative humidity. That is when the humidity is high, the moisture content is high and vice versa. A wet solid brought into contact with air of lower relative humidity has the same characteristic. The solid loses moisture and comes to equilibrium with the air. When the air is more humid than the solid, the solid absorbs moisture from the air until equilibrium is attained. The movement of moisture between the solid and air of different relative humidity is independent of temperature. It is therefore advisable that palm kernel nuts' oil should be extracted immediately after drying in order to avoid re-absorption of moisture from the surrounding air.

5.0 CONCLUSION

This design provides a scientific approach to drying under controlled temperature, and a neat drying environment that will allow heated air to blow over the product to be dried. From this work the following conclusions were drawn:

1. The different experiments carried out show that the drying rate of any product depends on

the length of time it spends in the drier and the preset temperature of the drier.

2. The performance of the electronic instrumentation and control system of the drier was satisfactory. Presetting the drier at 100°C, a maximum period of 50 minutes was required for drying palm kernel nuts. For a drier at 80°C, the drying period increased to 60 minutes. Drying at a lower temperature than 60°C required a drying period longer than 60 minutes. At these temperatures, extraction of optically purer and cleaner palm kernel oil than hitherto extracted by local manufacturers is possible.
3. Conservation of energy during the drying process was well achieved. However, the drying chamber should provide wide enough opening for both inlet of air and outlet of air in order to reduce the humidity of the drying chamber and hence speed up drying process. In the drier designed in this work, heat loss was reduced to minimum which later resulted to high humidity inside the chamber since the vapour that escaped out of kernels could not find enough route to escape out of the dryer. This however lowered the drying rate.
4. The recommended ventilation type to adopt for many products (especially those whose properties are damageable with heat) is natural convection at 10-30°C above ambient temperature. The benefit of this is the preservation of the physical, biological and the chemical properties of the material been dried since the temperatures deviate only a little from the natural means of drying which is sun drying.
5. It is possible to further reduce the drying period if a wet bulb thermometer is not in the drying chamber and the relative humidity of the product is determined using an electronic humidity sensor. It is also possible to increase the number of heaters to make the drying faster.
6. Increasing the size of the drier can increase the capacity of the tray drier. The capacity extension most favourable for tray driers is in horizontal direction. The equipment can be adapted to the required size by some design changes for capacity and a more efficient fan for hot air circulation. The control circuit or the electronic instrumentation remains the same.
7. By merely changing the preset temperature the equipment can be adapted to dry many other agricultural products such as coffee, beans, cocoa and maize to mention a few even at temperature higher than 100°C. In drying grains for future planting, care must be taken not to kill the embryo. It is advisable that in grain drying, the temperature is kept down to not more than 50°C [7]. On the other hand, in drying items like fish, meat, yam, chips etc, charring due to excessive heating must also be avoided, as it spoils the texture and quality of the items. For such items, temperatures between 80°C to 100°C are good.

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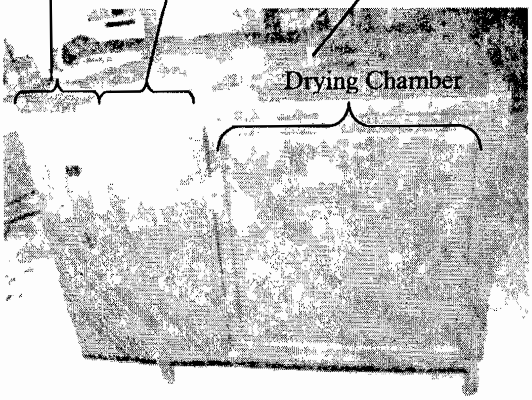


Figure showing the complete drier.

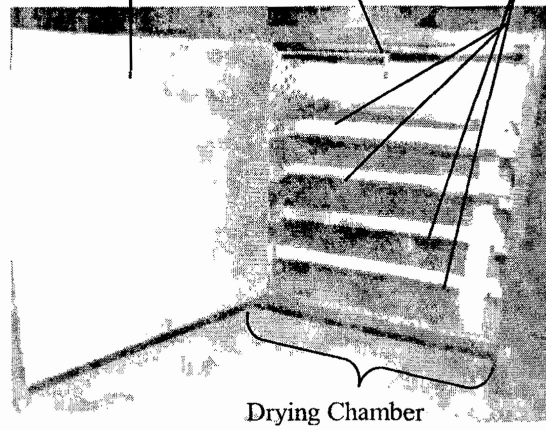


Figure showing drying chamber and trays.

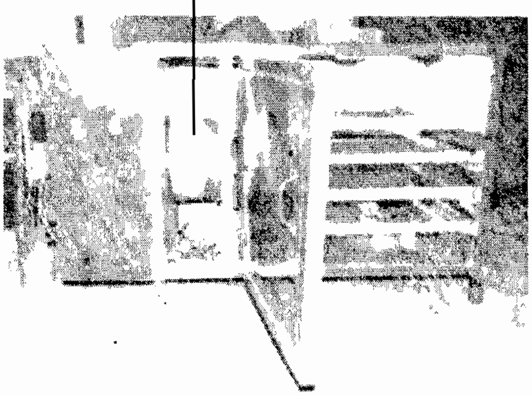


Figure showing the' heater section' with the 'air guard'.

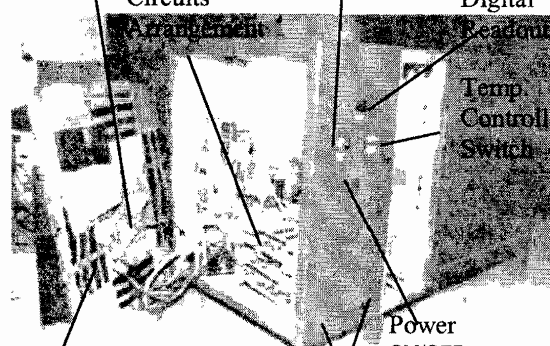


Figure showing the electronic control and instrumentation circuits.

Figure 1 Pictures showing the different parts of the drier

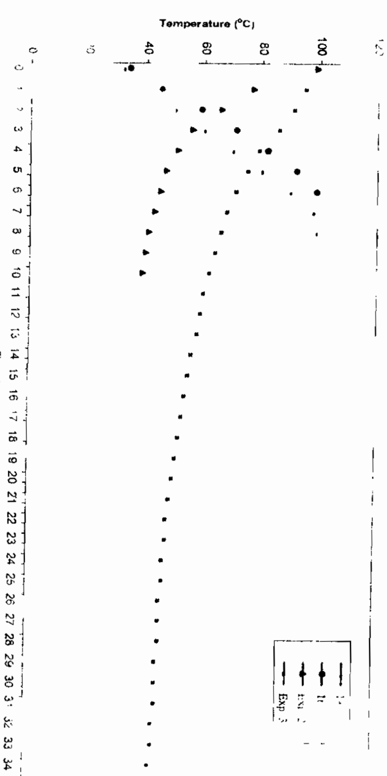


Figure 2: Graph of Temperature - Time Response

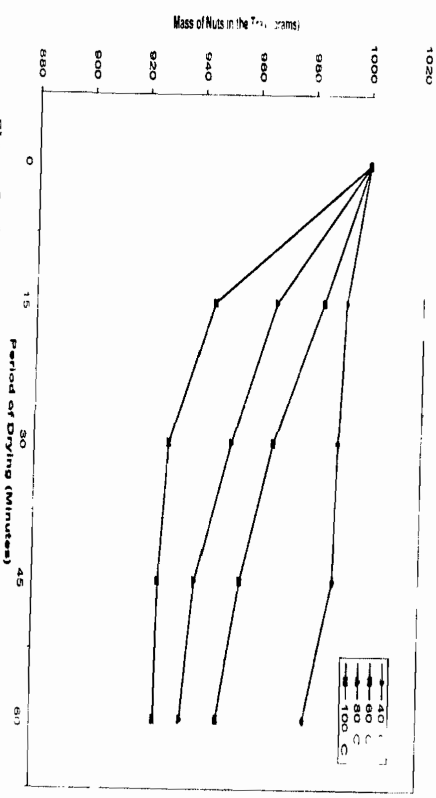
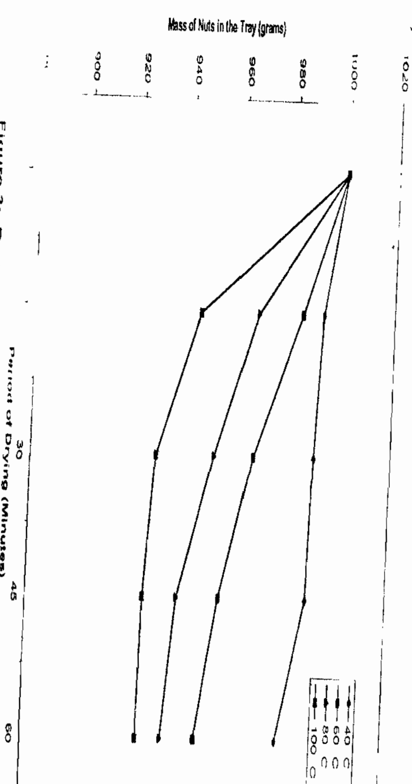


Figure 3: Drying curves of kernels at different constant temperatures



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