DEVELOPMENT OF A SOLAR DRYER FOR A PROCESSED LOCUST BEAN

BY

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(ABE/13/1048)

A PROJECT REPORT

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DEDICATION

This project work is dedicated to God the Father, the Son and the Holy Spirit who makes all things beautiful in His own time.

Also to my loving parent Mr and Mrs M. O. Tijani and my siblings Kehinde, Idowu and Olajumoke for their support and encouragement.

CERTIFICATION

This is to certify that TIJANI, Taiye Muminat, an undergraduate student in the Department of Agricultural and Bioresources Engineering, Federal Universiy Oye-Ekiti with Matriculation Number ABE/13/1048, has successfully carried out and completed this project work in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering in Agricultural and Bioresources Engineering. The work embodied in this report is original and has not been submitted in part or full for any other Diploma or Degree in this University or any other University.

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ABSTRACT

Drying is the oldest method of preserving agricultural products and it is an energy intensive process. High prices and shortages of fossil fuels have increased the emphasis on using alternative renewable energy resources. Drying of agricultural products using renewable energy such as solar energy is environmental friendly and has little environmental impact. Development of solar drying has brought a techniques and equipment for fast drying of various agricultural product foods. Product dried in solar dryer are superior in quality (colour and flavour). Though the same superior quality product can be obtained by using electricity or electrical power, but the electric operations are expensive and are not within the reach of our rural and tribal population.

Solar dryer is an equipment for drying agricultural product under controlled conditions. The controlled drying means controlling the parameters like drying air, temperature, humidity, drying rate and air flow rate. The cost of production for this project work is ₦188, 000. 00.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

Small farmers in developing countries produce vegetables, fruits and fish as major agricultural and aquatic products. These products are intended mainly for domestic consumption and sale in the local market. However, in case of overproduction, tremendous losses occur because farmers have neither access to markets in big cities nor to the international market due to poor product quality and absence of good marketing and distribution system. As an alternative to the marketing of fresh fruits and vegetables, small farmers can produce dried products. In Africa many species of trees serve as sources of food and for medicinal purposes to indigenous people. Some of these trees provide ecological services including microclimate amelioration and soil fertility. They serve as source of income for many poor people in the rural areas; one of these trees is *Parkia biglobosa* (African locust bean tree) (Igba in Yoruba language). Farmers manage and protect this tree for their nuts and fruits. The tree has been used both locally and internationally in drug manufacturing and cosmetics production. Despite the important uses, the populations of this tree is reducing and it remain semi- or undomesticated this was supported by (Ojewunmi *et al.*, 2016).

African locust bean tree was named *Parkia biglobosa* by Robert Brown, a Scottish botanist in 1826 after Mongo Park, a Scottish surgeon who explored West Africa in 1790's. Mongo Park gave this tree a local name 'nitta' (Uaboi-Egbenni *et al.*, 2009). In 1995, research indicated that there were about 77 more species. African locust been tree was described by Robert Brown, as a genus of flowering plants in the legume family, Fabaceae, which belongs to the sub-family Mimosoideae and Leguminosae with the genus Parkia and botanical name *Parkia biglobosa* (Abdoulaye, 2012). Parkia bicolor, Parkia filicoidea, Parkia clappertoiana and *Parkia biglobosa* are other species of the genus of *Parkia biglobosa* which can also be fermented to produce food condiments for flavouring which also for adding good aroma to food. It was reported that fermented African locust bean seeds is a leguminous plant with an outstanding protein quality. The protein and amino acid composition have been reported by several researchers (Ojewumi *et al.*, 2016).

1.2 Aim of study

The aim of this project is to evaluate the performance of the solar dryer. To reduce unnecessary field losses therefore increasing the useable economic shelf life and preserving the quality of the product. The material for its construction would be locally sourced. The dryer has to be easy to operate with low maintenance cost. The choice of the latitude orientation makes the project easy to be carried out at Federal University Oye-Ekiti (FUOYE), though areas with similar characteristics as Federal University Oye-Ekiti (FUOYE) can adopt the technology with very little variation that might be experience in the performance of the dryer.

1.3 Statement of problem

Small scale farmers find it difficult to store their products using automated dryers since this technique needs electrical energy, it is not beneficial to the small scale farmers who cannot afford the electricity or other fuel for drying. Electricity grid is not available to an average farmer in the rural area. The cost of fueling the generators for drying is not economical.

1.4 General objectives of study

The general objective of this study is to develop an active solar dryer in which leguminous crops such as locust beans are dried simultaneously by both direct radiations through the transparent walls and roof of the cabinet and by the heated air from the solar collector. The problems of low and medium scale processor could be moderated, if the solar dryer is designed and constructed with the consideration of overcoming the limitations of direct and indirect type of solar dryer. So therefore, this work will be based on the importance of indirect active solar dryer which is reliable and economical, also to develop an indirect active solar dryer using locally sourced materials and also to evaluate the performance of this solar dryer.

The specific objectives of this work are as follows;

i. Design a solar dryer enabling the introduction of low cost and locally manufactured solar dryers to provide a promising alternative in reducing the grand postharvest losses.

ii. To fabricate the solar dryer and also identify systems that are simple, easy to use in environments of rural communities in developing countries.

iii. To evaluate the performance of the dryer.

1.5 Justification of the study

Having found out that drying is very essential for agricultural products which is significant in the reduction of product volume and preservation promoting it efficiency in both transportation and storage of food product. This waste may be reduced considerably if the products are dried before they are transported to the market. Most crops are being sun-dried on the ground; this is however a slow ineffective method because it takes days to achieve tangible results. Also, crops are exposed to attack by bacterial and the like. Ordinary sun drying method was found to be tedious, time wasting, wastage in terms of produce and consequently having a very low hygienic level.

The direct exposure to sunlight, or more precisely ultraviolet radiation, can greatly reduce the level of nutrients such as vitamins in the dried product. African locust bean seed (Parkia biglobosa), Abelmoschus esculentus (okro), Zea mays (maize), which are used extensively in Nigeria.

This project presents the design, construction and performance of active solar dryer for food preservation. In the dryer, the heated air from a separate solar collector is passed through a vegetable bed, and at the same time, the drying cabinet absorbs solar energy directly through the transparent walls and roof. The results obtained during the test period revealed that the temperatures inside the dryer and solar collector were much higher than the ambient temperature during most hours of the day-light. The temperature rise inside the drying cabinet was up to 74% for about three hours immediately after 12.00hr (noon). The dryer exhibited sufficient ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product.

1.6 Scope of study

To carry out literature review on drying and to obtain some data information required for the development of the solar dryer. And also to select suitable materials for the fabrication of the solar dryer, to prepare a neat and detail working drawing and to discuss the results of the performance analysis of the solar dryer and lastly to make other possible recommendations.

1.7 Limitation

The limitations of the project are as follows;

i. The work is not compared with the efficiency of other dryers.

ii. A backup heating system is not provided for products requiring continuous drying.

CHAPTER TWO

2.0 LITERARURE REVIEW

2.1 Origin of African locust bean

The African locust bean tree with the botanical name *Parkia biglobosa* is a perennial deciduous tree that is fairly widely distributed all over the natural grassland of Northern Nigeria (Sobande, 2013,) (Ojewumi *et al.,* 2016). The tree starts to bear fruits from five to seven years after planting. It is planted mainly for the food value of its fruit. It grows in the savannah region of West Africa. The tree has a height ranging from 7 to 20 m; in some exceptional cases some might reach heights of up to 30m, with a wide spreading umbrella-shaped crown (Teklehaimanot, 2004), (Ojewumi *et al.,* 2016). Its performs an essential function ecologically in cycling of from deep soils, and in holding the soil particles with the aid of the roots to prevent soil erosion (Alabi *et al.*, 2005). The tree also provides shade for man. The tree requires an altitude of about 300 metres with an average rainfall of 400 - 700 millimeters per year and an average mean annual temperature of 28 °C. It prefers well-drained, deep, cultivated soils, but can also be found on shallow, skeletal soils and thick laterites(Database.prota.org, 2014).

Figure 2.1: African Locust Bean Tree (*Parkia Biglobosa*) (Igba tree).

Source: (Sobande, 2013 and Ojewumi *et al.*, 2016)

African locust bean tree was named Parkia biglobosa by Robert Brown, a Scottish botanist in 1826 after Mongo Park, a Scottish Surgeon who explored West Africa in 1790's. Mongo Park gave this tree a local name 'nitta' (Uaboi-Egbenni *et al.,* 2009). In 1995, research indicated that there were about 77 more species. African locust been tree was described by Robert Brown, as a genus of flowering plants in the legume family, Fabaceae, which belongs to the sub-family Mimosoideae and Leguminosae with the genus *Parkia* and botanical name *Parkia biglobosa* (Abdoulaye, 2012). *Parkia bicolor, Parkia filicoidea, Parkia clappertoiana* and *Parkia biglobosa* are other species of the genus of *Parkia biglobosa* which can also be fermented to produce food condiments for flavoring and adds good aroma to food. It was reported that fermented African locust bean seeds is a leguminous plant with an outstanding protein quality. The protein and amino acid composition have been reported by several researchers (Cook *et al.*, 2000).

2.1.1 Agronomy of African Locust Bean Tree

African locust bean tree *(Parkia biglobosa)* is a perennial tree which belongs to sub – family mimosodee and family leguminosae (now fabaceae) (Ojewumi *et al.*, 2016). Locust bean tree is a leguminous crop peculiar to the tropics. The tree is not normally cultivated but can be seen in population of two or more in the savannah region of West Africa (Hopkins, 1983). It is prominent in entire savannah region of West Africa (Yudkin, 1985). It grows in savannah region of West Africa up to edge of Sahel zone (Campbell-Platt, 1980). Dalziel (1963) and Keay (1989) reported that locust bean tree extends from Senegal to Sudan and its habitat is in savannah land as it is characteristic of transition areas from sahelian to Sudanian eco-zones locally on farmlands. It is common in Nigeria particularly in the Northern and South Western Nigeria (Odunfa, 1982). Locust bean tree is found throughout the savannah lands of North Central Nigeria covering Benue, Kaduna, Kwara, Kogi, Nassarawa and Plateau States (Tee *et al.*, 2009). The tree is common around villages where it is left standing when land is cleared or sometimes planted (Dalziel, 1937). A matured African locust bean tree of 20 to 30 years can bear about a ton and above of harvested fruits. Musa (1991) reported that the tree can start to bear fruits from five to seven years after planting. The tree is about 7 to 20 metres high and bears pods that occur in large bunches and vary from 120 to 300 mm in length. African locust bean tree fruits during the months of December to March of the year.

2.2 Harvesting of the African Locust Bean Pod

Harvesting technique of African locust bean is universally same by use of a light hooked pole. The farmer climbs up locust bean tree and leans on bigger branches and stretches out the hooked pole to reach every bunch (Akande *et al.*, 2010).

Mature pods of African locust bean occurred in large bunches. Each pod varies between 12 and 30 cm in length and 12 – 25 mm in breadth (Adewumi, 1997). The pod has tough pericarp while the seeds have hard testa (Simonyan, 1988). The pod is tough and fibrous, enclosing a soft, powdery, yellowish pulp in which small seeds are embedded. Each locust bean tree yields about 25-52 kg of pods from which 6-14 kg of bean may be collected (Odunfa, 1982). The morphology of the locust bean fruit is given in Fig 2.2.

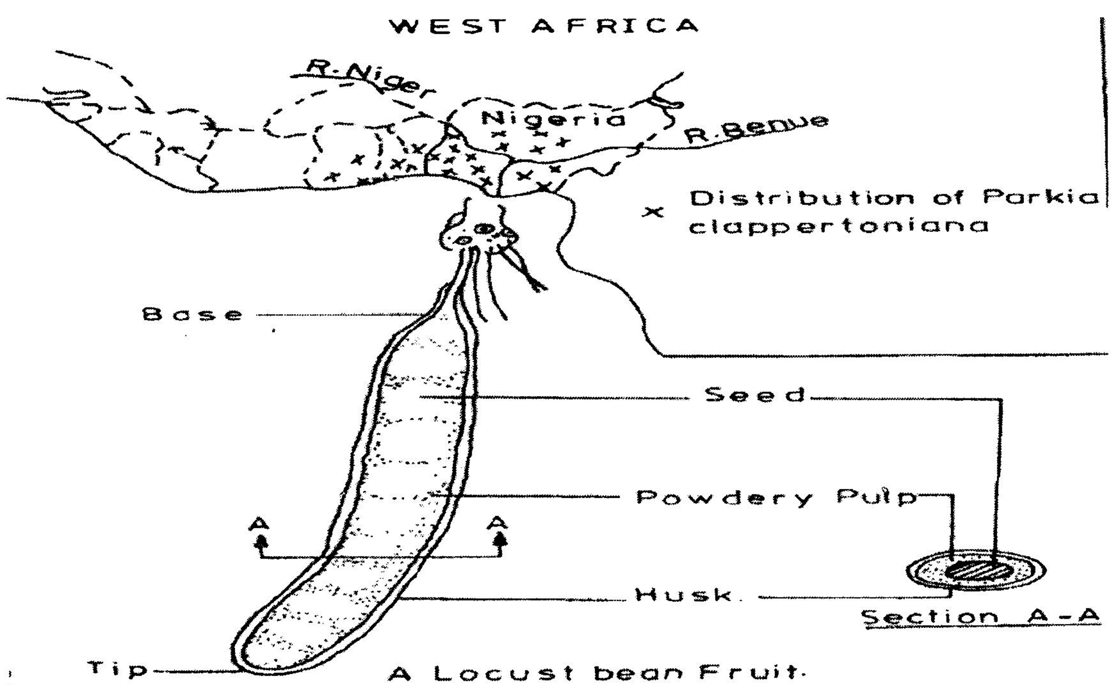


Fig 2.2: Distribution of Parkia Clappertoniana in Nigeria and a Parkia Fruit

Source: (Simonyan *et al.*, 2012)

2.2.1 The African Locust Bean Seed

The multipurpose African locust bean tree has seeds with a hard testa and these seeds have mean weight of about 0.3 g / seed and cotyledons form about 70 % of the weight. These seeds are borne in pods that may have up to 30 seeds embedded in a yellow pericarp. The colour of the pods change from pink brown to dark brown as maturity sets in. African locust bean tree also bears alternate, dark green bi-pinnate leaves and hermaphrodite flowers (Adewumi, 1997). African locust bean seeds size varies within pod, with those at the centre being largest. The seeds vary in shape, some are oval and more or less flat and others are nearly spherical. The seed has a tough dark or brown coat with a hard golden – yellow cotyledon (Adewumi, 1997). The seeds are encased in a tough, elastic and relatively thick coat that has a very low permeability. The low permeability restricts free and easy movement of water through the coats. Interface adhesive force binding the coat to the seed is relatively high. This makes dry hulling of locust bean seed difficult and inefficient. Most of the beans are shattered when dehulled in a dry condition (Adewumi and Igbeka, (1996)). Locust bean seed is widely used for its remarkable nutritional and dietary value. The seeds are rich in protein, lipids and vitamin B2 and when fermented are rich in lysine. The fat in the beans is nutritionally useful (approximately 60 % unsaturated). The fermented locust bean seeds are commonly used in soups and stews (Owolarafe *et al.*, 2011). It is a culinary product that can be used to enhance or intensify meatiness in soups, sauces and other prepared dishes (Ohenhen *et al.*, 2008). African locust bean (*Parkia biglobosa*) is presently under-exploited tropical legume despite its promising economic value Elemo *et al.*, 2011. The high cost of animal protein has directed interest towards several leguminous seeds. Among the plant species, legumes are considered as the major sources of dietary protein (Chukwu *et al.*, 2010). They are consumed worldwide especially in developing and under-developed countries where consumption of animal protein is limited as a result of economic, social and cultural factors (Esenwah and Ikenebomeh, 2008). With high contents of protein, legume condiments serves as a tasty complement to sauces and soups and can even substitute fish or meat (Chukwu *et al.*, 2010). African locust bean seed is a grain legume which is fermented and added to soups and stews as condiment to enhance the flavour and nutritional values.(Chukwu *et al.*, 2010). Odunfa (1981) reported that fermented locust bean seed is commonly consumed in Ghana, Nigeria, Sierra Leone and Togo. It is called „Iru" in Yoruba, „dawadawa" in Hausa and „ogiri-igala" in Igbo parts of Nigeria. It is referred to as „kinda" in Sierrra Leone and „Kpalugu" in Ghana.

2.3 Local Processing and Art of Production of Products from Locust Beans

African locust beans can only be eaten after processing to remove toxins and anti-nutrients (Olaoye, 2010a). Major processing techniques involve harvesting, decorticating, depulpping and drying to obtain the locust bean seeds that represent the major raw material from this important crop (Olaoye, 2010a). The local processing method is shown in Fig 2.3. According to Olaoye (2010a), local production of African locust bean products is mostly rigorous, time consuming and unhygienic. The procedure had witnessed little or no substantial technological transformation and progress in the manufacturing techniques.

Recent popularity of iru as a condiment has attracted research interest in development of machinery to handle some of its unit process operations. Traditional iru processing is still being carried out at a domestic level.

2.4 Primary Crop Processing and Secondary Food Processing for Production of Locust Bean Products

Processes involved in production of Iru condiment which represents one of the major locust bean products right from the raw substrate are highlighted and shown in flow chart Figs. 2.4 and 2.5. Modern processing techniques are required to improve on the traditional methods of processing and fermentation of the seeds (Olaoye, 2010a). Good-quality raw materials that have been efficiently graded and sorted, simple equipment, optimum conditions, and attractive packaging are the key requirements of a food industry (Olaoye, 2010a). Appropriate processing conditions need to be developed to subject the African locust bean to a form that the produce can be stored with a relatively long storage life. These conditions can also help to eliminate pests and micro-organisms that cause spoilage. Processing stages are identified as primary crop processing and secondary food processing. It has been observed that each stage need appropriate machine intervention for effective product development (Olaoye, 2010a).

Primary crop processing involves drying, decorticating and de-pulping of locust bean seeds from the pod. These processes are to enhance seed quality and subject it to a condition that will improve further food processing. Primary crop processes are to condition the seed into an intermediate state that will encourage long storage life of the finished crop product (Olaoye, 2010a).

Secondary food processing is to convert locust bean seed from the intermediate finished product into desired cube which requires fermentation and cubing operations (Olaoye (2010a).

Fig 2.3: Harvested Locust Bean under Storage Condition

Source: Olaoye (2010a) and Simonyan (2012)

Olaoye (2010a) gave two major challenges involved in production and processing locust bean as production bottleneck associated with the crop's seasonality and also traditional processing procedure with the attendant low quality and quantity of the derived products.

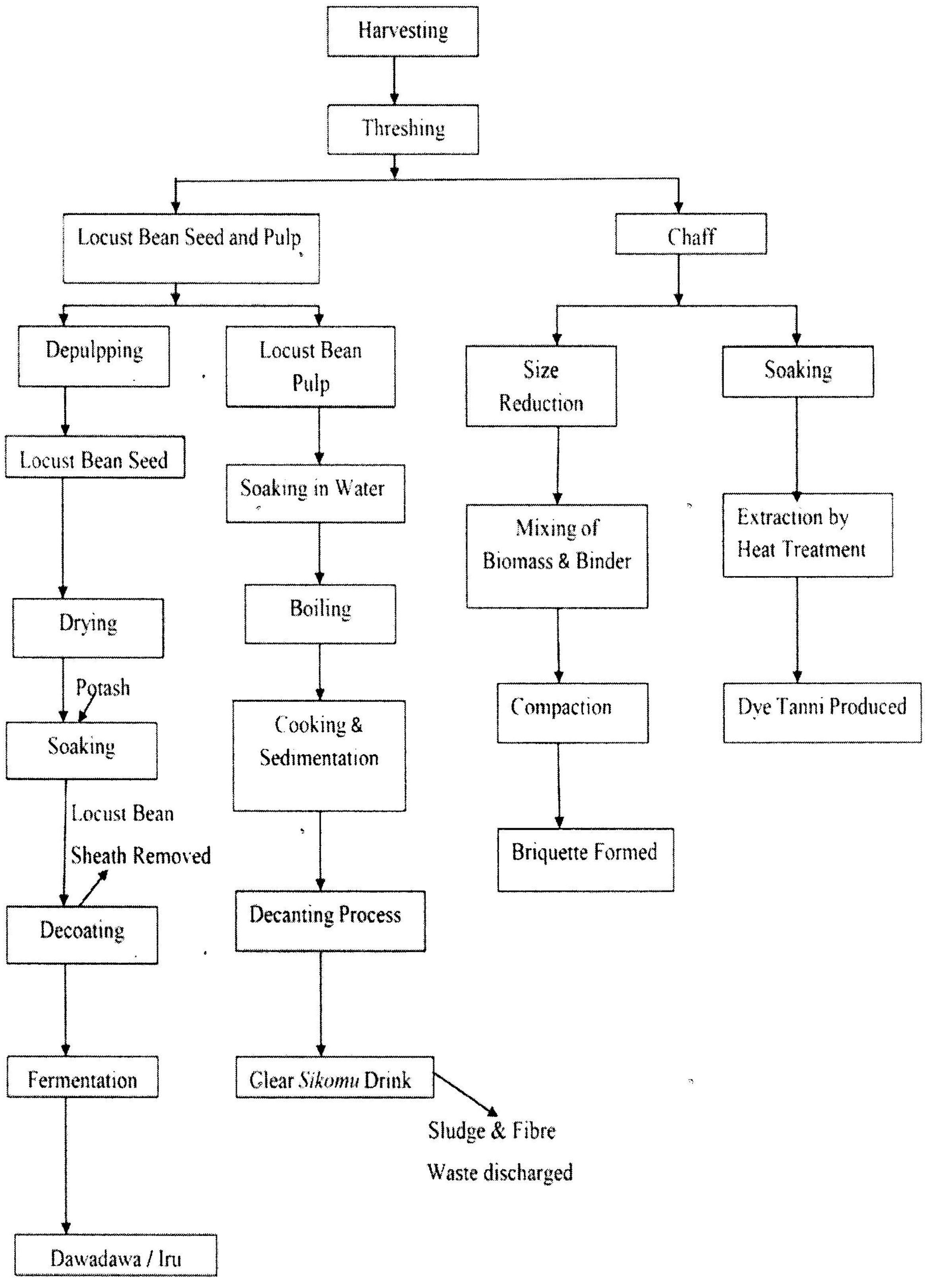


Fig 2.4: Processing Procedure for Production of Major African Locust Bean Products.

Source: Olaoye (2010a) and Simonyan (2012)

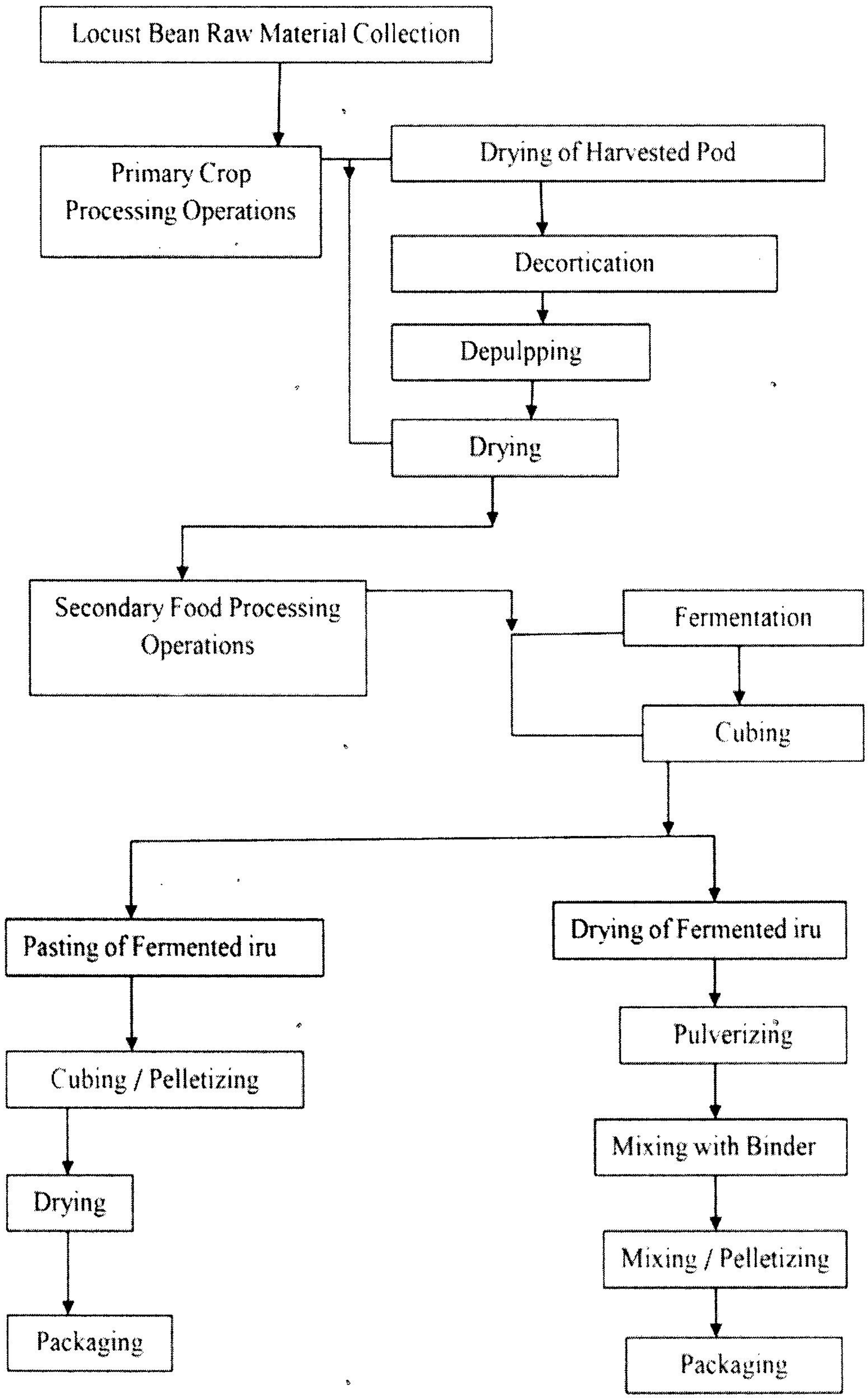


Fig 2.5: Flow Chart of Unit Operations Involved in the Iru Cube Production

Source: Olaoye (2010a) and Simonyan (2012)

2.4.1 Uses and Importance of African Locust Bean Tree

High cost of animal protein has directed interest towards several leguminous potential sources of vegetable protein for human (Esenwah and Ikenebomeh, 2008). Among plant species, grain legumes are considered as major source of dietary proteins. African locust bean seeds are rich in protein and are usually fermented to a tasty food condiment called dawadawa which is used as a flavour intensifier for soups and stews and also adds protein to protein-poor diets (Ikenebomeh and Kok, (1984)); Odunfa, (1986); (Dike and Odunfa, 2003).

Locust bean tree plays a vital role in stabilizing the soils in farming areas and cycling nutrients from deeper soil layers, as well as by providing shade (Campell-Platt, 1980). As a leguminous plant of sub-family Mimosoideae, it also fixes atmospheric Nitrogen (Cobley and Steele, 1976). African locust bean tree has a high nutritional economic, industrial and medicinal value (Adewumi, 1997). The most important use of African locust bean tree is found in its seed which is a grain legume. The husks and pods have been reported as good food for livestock (Douglas, 1996), and (Obiazoba, 1998). The pod shell traditionally is used to extract a substance that helps to harden beaten natively made house floors and is an important source of tannin for leather industry. The yellow powdery pulp is rich in carbohydrate (Oladele *et al.*, 1985) and rich in oil suitable for the manufacture of soap (Owoyale *et al.*, 1986) and is used in the production of a native gruel (Kunnu) (Musa, 1991). The presence of fibres in the husk, together with tannins makes it a good raw material for production of particle board (Owoyale *et al.*, 1986). The leaves are rich in Nitrogen and used as feed for livestock and manure (Adewumi, 1997). The bean coat is used with indigo dye to improve the lustre of fabric, while the tree bark yields red tannin for dying leather. Carbon gum is extracted from the bean and added to foods and cosmetics as thickeners and emulsifiers (Yudkin, 1985). The dried pods could be used as fuel.

The embedded yellow pulp of the fruits sometimes called dozim have a high energy value which is used as sweetener since it contains 60 % sugar (Audu *et al.*, 2004). It is also a water purifier and is taken for fevers. The fruit is a source of food during drought. The leaves are edible and sometimes mixed with cereal and are added in lotions for sore eyes burns, haemorrhoids and toothache. Medicinally, the bark is used as a mouth wash and also macerated in baths to cure leprosy. It is used for a wide range of ailments such as malaria, diarrhoea; jaundice (Audu *et al.*, 2004). The tree is a good source of timber though it is rapidly spoiled by pests (Owolarafe *et al.*, 2011).

When processed the African locust seeds constitute an important condiment that adds taste and flavour to soup (Oje, 1993). The seeds (karwa- Hausa; ngin- Ham; Iyere- Yoruba) are traditionally used as food condiment (dawadawa- Hausa; Iru- Yoruba; soumbala in Burkina faso, Mali, Cotdevoire and Guinea, Ogiri in the Eastern Nigeria). Dehydrated "tempeli" is an equivalent fermented product in Indonesia (Steinkrans *et* al., 1965). The seeds contain about 26 % protein and are rich in Calcium (Vickery and Vickery, 1979). It is used as a food condiment and is a good substitute for meat because it is high in protein, fat, and vitamins contents (Obizoba and Atu, 1993) and it is rich in tannin and mineral contents (Obizoba and Atu, 1993), (Enujiugha and Ayodele - Oni, 2003).

Nutritionally, African locust beans are important particularly in the third world countries where the need for protein supplementation is high for both adults and infants. The average daily per capital intake of dawadawa among some Hausas in Northern Nigeria constitutes 1.4 % of daily calories and 5 % of the protein (Simeon, 1976). The daily per capital intake of protein from dawadawa is high than from poultry but less than from beef (Ogunbunmi and Bashir, 1980). Thousands of West African women earn cash income by making daddawa in low capital small scale enterprises at home and selling it at local market. The condiment contributes to calorie and protein intake (Simmons, 1976); Umoh and Oke, (1974) and is generally added to soups as low meat substitute by low- income families in parts of Nigeria (Odunfa, 1985).

African locust bean is being used as food flavours and additives. It is a raw material for the production of cubed food flavour such as dawadawa cube which competes favourably with magi cube (Adewumi, 1997). Throughout the West African savannah, daddawa (a Hausa word, also dawadawa) or "local magi" is eaten regularly in soups and stews. Daddawa is tasty and protein

–rich seasoning which is used like stock cubes or cheese in European and North American cooking (Waters-Bayer, 1988).

African locust bean tree serves essentially for economic and ecological purposes (Tee *et al.*, 2009). Economically, the tree provides income and employment to many household members and particularly women who are more involved in processing and marketing of locust bean products. Trading activities are in raw seeds, fermented food condiment, charcoal and firewood among others provides reasonable income and employment. Ecologically, African locust bean tree plays a vital role in nutrients recycling and erosion control. The tree acts as buffer against the effect of strong wind or water runoff that usually causes damage to crops and soil. Being leguminous plant, it fixes Nitrogen in the soil thereby enriching the soil nutrients content. It also provides medicinal services and energy supply (Tee *et al.*, 2009). Figure 2.2 gives the constituents of Parkia Clappertoniana fruit.

All the parts of African locust bean tree are useful (Olaoye, 2010). The pods are used for production of locust bean gum. This gum is used around the world as a thickening agent and stabiliser in many food products such as mayonnaise and within textile industry as a print thickener (Glasson Grain Ltd, 2006). Fermented bean pulp waste contained protein 11.75 %; ash, 15.86 %; crude fibre, 21.55 %; starch, 32.14 %; dry matter, 93.5 % and moisture, 6.5 % while unfermented pulp contained protein 10.13 %; ash content, 14.14 %; crude fibre 22.63 %; starch, 28.20 %; dry matter, 92.5 % and moisture, 7.5 %. Unfermented locust pulp waste exhibited a stronger binding effect than corn starch after 12 weeks storage (AkegbejoSamsons *et al.*, 2004).

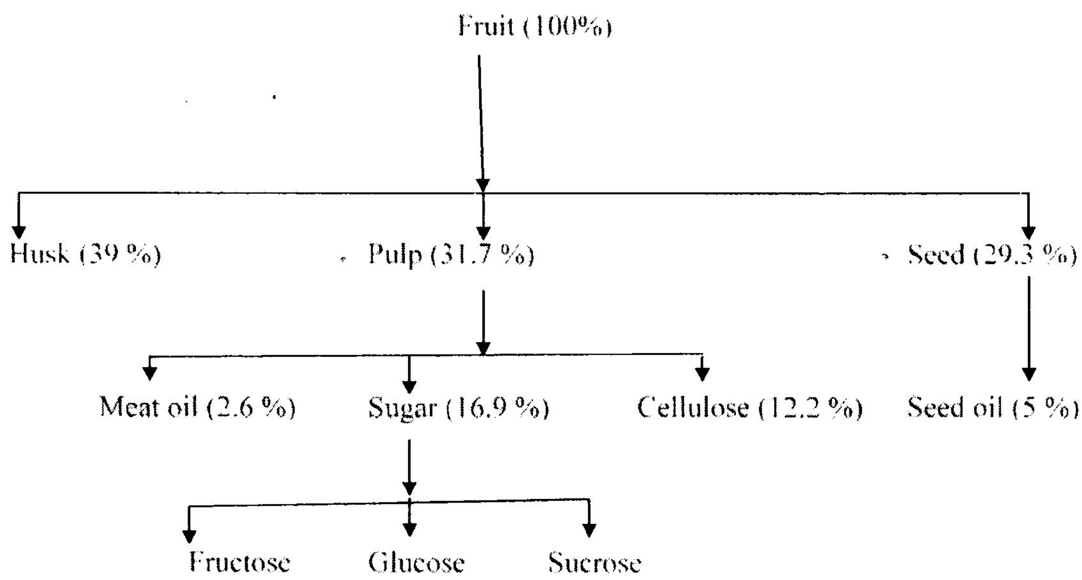


Fig. 2.6: Constituents of Parkia'Clappertoniana Fruit

Source: Owoyale *et al.*, 1986

Hopkins (1983) observed that beside the direct use in human nutrition, the pods of P. Clappertoniana are used as food for domestic stock. He gave various potentially toxic substances present in the fruit as:

i. A crystalline substance, parkine, which is isolated from powdered pods of P. clappertoniana. Its physiological action when injected into animals is similar to that of alkaloids mimosine and physostignine.

ii. Analyses of seeds showed that several sulphur containing non- protein free amino acids are present, including nucleonic acid.

iii. Lectins found in the seeds of African Parkia agglutinate human and some animal red blood cells.

However, despite the.importance, use of African locust bean seeds like some other legumes as protein source is limited by the presence of anti- nutritional factors which are a diverse range of naturally occurring compounds in many tropical plants (Esenwah and Ikenebomeh, (2008)). The anti- nutritional factors cause poor protein digestibility in man and animals and are capable of precipitating other deleterious effects. Manifestations of toxicity from the consumption of legumes containing anti- nutritional factors range from severe reduction in food intake and nutrient availability or utilization, to profound neurological effects and even death (Osagie, 1998). Esenwah and Ikenebomeh (2008) recommended that to improve nutritional quality and organoleptic acceptability of leguminous seeds, African locust bean inclusive, processing techniques must be employed to reduce or destroy the anti-nutrients presents in them. They mentioned some commonly used processing techniques such as soaking in water, boiling at high temperatures in water, alkaline or acidic solutions, sprouting, autoclaving, roasting, dehulling, microwave treatment, steam blanching and fermentation.

2.5 Prospects of Mechanization of African Locust Bean Production and Processing

Hesseltine and Wang (1979) reported that in order to increase the production of iru, it is necessary to modernise production style and optimise processing conditions as it will guarantee improved and consistent flavour and increased shelf life Mechanizing the processing of African locust bean into condiment has a great deal of merit (Simonyan, 1988) as it will:

i. Improve or reduce drudgery associated with processing
ii. Improve the quality and acceptability of iru condiment
iii. Improve iru condiment preservation for long term use
iv. Enhance rural economy.

Oni (1986) observed that decorticating by hand is labor intensive, grossly inefficient and time consuming. Hence a simple and relatively inexpensive decorticating machine must be developed to overcome this labor bottleneck.

2.6 Traditional Food Processing Technologies

Traditional technologies of food processing and preservation date back thousands of years and unlike electronics and other high technology industries, they preceded any scientific understanding of their inherent nature and consequences (Hulse, 1983). Traditional foods and traditional food processing techniques form part of culture of the people. Traditional food processing activities constitute a vital body of indigenous knowledge handed down from parent to child over several generations (Aworh, 2008). According to Aworh (2008) simple, low cost, traditional food processing techniques are bedrock of small – scale food processing enterprises and their contributions to the economy are enormous.

Agro-processing plays strategic role of imparting durability, enhancing product differentiation and generally adding value to agricultural commodities in order to prepare them for global marketing (Ngoddy, 2007).

2.7 Applications of solar driers

Solar drying methods as applied to foods have earlier been reviewed by Bolin and Salunkhe (1980, 1982). The former surveyed methods of solar drying having varying levels of technological sophistication and compared the thermodynamics of conventional dehydration with those of solar drying. It has been exhaustively reviewed the drying methods using only solar energy, as well as those using solar plus and auxiliary energy source, besides discussing the quality and economic aspects, suggesting that to produce a high quality product economically it must be dried fast without excessive heat (Singh *et al.*, 2011; and Jangam *et al.*, 2011)

Imre (2004) described in detail the construction principles of solar dryers and flat plate collectors along with their economics and performance evaluation. Several authors have studied the usability and performance of various types of solar dryers, energy storage systems (Kalra *et al.*, 1981; and Miller, 1985) and pretreatment techniques (Islam *et al.*, 1982; Moyls, 1986; and Vaghani, 1986). Cheema and Ribero (1978) studied the comparative performance of three dryers for the drying of cashew, banana and pineapple and found that optimum combination of solar and conventional drying is more suitable. To shorten the drying time Wagner *et al.* (1979) utilized the principles of parabolic reflector to increase the radiation on the product.

Bolin *et al.* (1980) discussed the relative merits of five experimental methods for the solar dehydration of fruits, namely: black wooden tray, solar troughs of various materials designed to reflect radiant energy onto bottom of black metal drying trays, cabinet dryers with slanted plate heat collectors with natural convection, utilizing inflated Polyethylene (PE) tubes as solar collectors with and without partial air recirculation; and PE semi cylinder with a fan blower to be used in inflated hemispheres or as a solar collector, to blow air over the fruit in a cabinet dryer. They reported that utilizing inflated PE tubes method was cheap, 38% faster than sun drying for apricots and could be used as supplementary heat source for conventional dryer.

Kalra and Bhardwaj (1981) described two simple models of solar dehydrator with the functions of direct and indirect dryers for mango products and vegetables which are well suited to rural conditions and small scale industries. Sun drying of grapes requires longer time to dry and also there is a browning, contamination and spoilage of the product when exposed to the open atmosphere (Pangavhane *et al.*, 1999, 2002; and El-Sebaii *et al.*, 2002). Natural convection solar dryers have been the subject of investigation by many workers for studying the drying behavior of several fruits and vegetables. Islam and Flink (1982), conducted experiments on potato at low air velocities as encountered in solar dryers and found that due to extensive external mass transport resistance in deep bed drying, the air flow behavior of the bed was more important than drying behavior of the pieces. Drying time increased less rapidly than increase in bed depth. On the basis of simulated solar drying experiments, Shakya and Flink (1986), concluded that drying rate of potato increased with increased inlet air temperature and/or air flow potential and overall productivity increased with increasing bed depth.

2.8 Benefits of Solar dryer

Since drying accounts for 90% of the total energy consumed in the developing world especially in the rural domestics section (GTZ. 2002 and Burgos. 2008), drying with solar energy is the most desirable option to the developing nations such as Nigeria. The environmental benefits of solar drying to wood burning energy source includes that it reduces CO_2 release from the burning firewood, preserve forest reserve by reducing cutting down of trees thereby reducing soil erosion, water pollution, loss of soil fertility and untimely desertification. There are social benefits of using solar dryer in areas where collecting fire wood can mean long hours of work and dangerous. The use of solar dryer can also help improve people's health since it can be used to sterilize food by heating to 65^0C. This can highly be beneficial to areas where people do not have access to safe food and often suffer sickness or death as a result of impure food consumption (Metcalf. 1999). In addition, many people suffer food poisoning and eye ailment as a result of extreme smoky baking condition in homes by using fuel wood. Solar drying is obviously smokeless and so eliminates this problem as well as reduces burns and other fire related injuries.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Design Consideration

The major considerations in the development of the solar dryer is it easy mode of operation and its resistance to environmental condition such that the solar dryer could easily be transported from one point to another and as well withstand thermal and mechanical stress for a long time. Ultimately, the solar dryer should be able to dry and preserve the quality of the food products such as locust beans. Another important consideration in the design is in the reflection orientation since the major factor influencing the collection efficiency of the solar dryer is the solar collector orientation. The design took into account the best material required for the construction of the food trays so as to prevent contamination of the food products.

3.2 Materials and Methods

The thickness of the metal sheet used in constructing the sides and the base of the solar dryer was 1.90mm and the thickness of the transparent sheet was 0.57mm. These thickness are used so that the solar dryer will not be too heavy. Each side of the solar dryer is lagged using tube that has already been glued to the metal sheet so as to prevent heat loss due to convection, heat escaping from its sides and the flow per seconds is now constant. The dimension of the drying chamber used was 700묄묄 × 700묄묄 × 360묄묄, while the dimension of the absorber plate was 2000mm×7 00mm× 200mm. There is a cone-like cover made at the top of the drying chamber. The inner part of the solar collector is painted black as to absorb heat and trap the heat needed for drying. A black surface is a good emitter and absorber of radiation.

For this project, the transparent material serves as a reflectors. Inside solar collector is a box which makes the transparent material slant at an angle of 17.7983^0. When radiation from the sun incident on the transparent material, it is reflected the opposite direction. The thickness of the glass used is 0.57cm. A thermometer was used to measure the temperatures of the solar collector and the ambient at different time intervals.

3.3 Construction of the solar dryer

The materials used for the construction of the mixed-mode solar dryer are listed above and they are cheap and readily available in the local market. The solar dryer consists of the solar collector (air heater), the drying cabinet, drying trays, fans and solar panel.

3.3.1 Component Description

Solar Collector

Solar collectors are used to convert direct and diffuse radiation from the sun into thermal energy (Jercan, 2006). It is a special kind of heat exchanger that transforms solar energy to heat. Energy is transferred from a distant source of radiant energy to a fluid (Duffie and Beckman, 1980). For applications requiring less than 80oC, flat plate collectors are widely used (Struckmann, 2008). Flat plate collectors are mechanically simpler and require little maintenance than concentrating type of collectors (Duffie and Beckman, 1980).Generally, flat plate collector designs consist of three major parts. These are transparent cover, absorber plate and insulation.

Cover plate: It is transparent sheet is made of 4 mm thick glass used to cover the absorber, thereby preventing dust and rain from coming in contact with the absorber. It also retards the heat from escaping (i.e forming a confinement for heated air) It is placed about 2.54 cm above the absorber.

Absorber plate: It is a metal painted black to absorb the incident solar radiation transmitted by the cover thereby heating the air between it and the cover. Here aluminum is chosen because it's quick response in absorption of solar radiation.

Insulation: It is used to minimize heat loss from the system. It is placed under the absorber plate. The insulator can withstand stagnation temperature, it is fire resistant and not subject to out-going gassing; and it should not be damageable by moisture or insect. Insulating materials are usually fiberglass, mineral wool, Styrofoam and urethanes, with at least 5 cm thickness.

Drying Trays: The drying trays are contained inside the drying chamber and were constructed from a double layer of fine chicken wire mesh with a fairly open structure to allow drying air to pass through the food items.

Drying chamber/ Compartment: Products are located on trays or shelves, normally it is made of opaque materials in the case of indirect or hybrid system of dryer. Solar radiation is thus not incident directly on the crop. Preheated air is warmed during its flow through the solar thermal collector; it is ducted to this chamber to dry the products. Because the products are not subjected to direct sunshine, localized heat damage, do not occur. This chamber sometimes is made of highly polished metal materials because of its good conductor of heat characteristic and smooth surface finish.

Fan system

Fan or blower can be installed before the collector or after the collector. In the systems, where it is connected between the collectors and the drying chamber, the collector works under slight negative pressure hence minimizing the effect of minor leaks if any developed with time. The fan aids the movement of air into the dryer. Positive pressure is maintained inside the dryer to avoid entry of dust and cold air into the dryer. Normally, fans may be powered with utility electricity if it is available, or with a solar photovoltaic cell.

Turbo-ventilator

This create a draught that enables heated air to flow upward in the solar collector, pass through the food stuffs arranged in trays taking out the moisture from the food. Wind driven turbo ventilators are used all over the world because of their low capital and installed cost, adaptability, high capacity per vent, and overall reliability. Operation is simplicity in itself. As the vent hood is rotated by the wind, the saturated inside air is exhausted through the vanes and the natural inward flow of heated air from the collector is boosted.

Chimney

This provides a means through which the dry heated air that has passed through materials being dried and exits the dryer are recirculated and heated further. Chimney has to have overhung in order to prevent rains or any insects from interfering with drying materials. Besides, turbo-ventilator can be fixed on top of it to aid draught built up.

3.3.2 The orientation of the solar collector

It is important to note that the orientation of the solar collector is relative to the direction of propagation of solar radiation. The tracking of the sun is through its altitude and azimuth angle, the design of the solar collector was based on the selection of the altitude and the azimuth angle. The Flat plate collector is always tilted and oriented in such a way that it receives maximum solar radiation during the desired season of use. The best stationary orientation is due south in the northern hemisphere and due north in southern hemisphere. Therefore, solar collector in this work is oriented facing south and tilted at 17.7983^{o} to the horizontal. This is approximately 10^{o} more than the local geographical latitude (Ikole-Ekiti a location in Nigeria, 17.7983^{o}N), which was according to Adegoke and Bolaji (2000), is the best recommended orientation for stationary absorber. This inclination is also to allow easy run off of water and enhance air circulation.

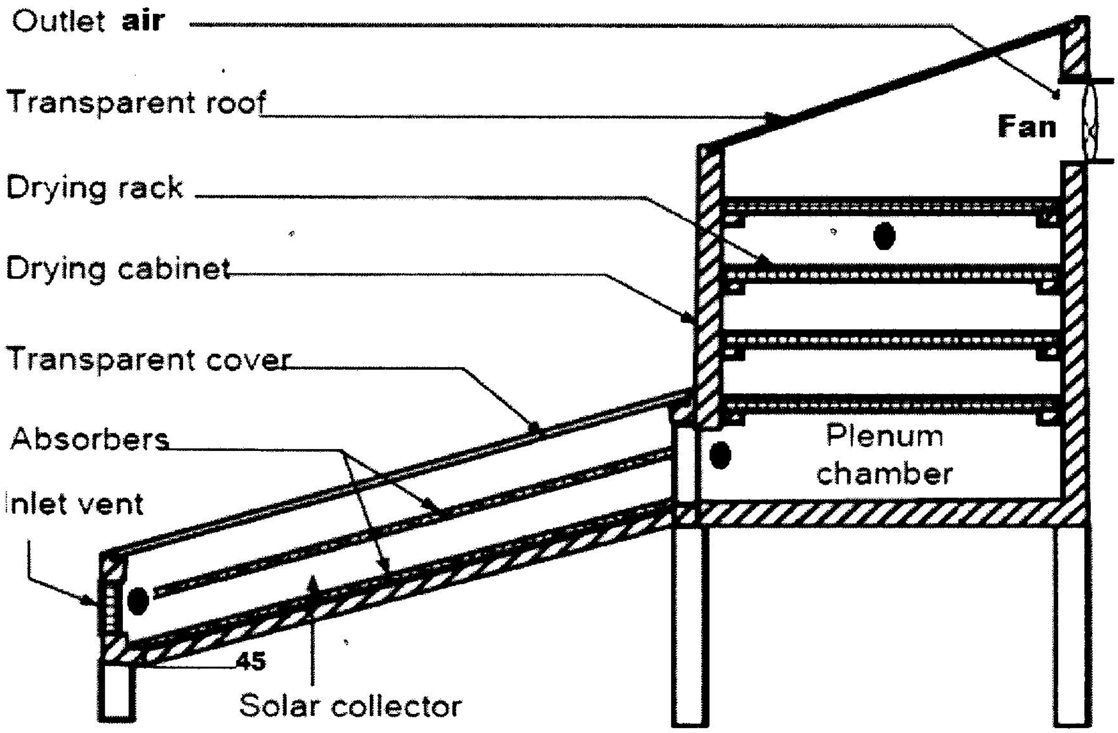


Fig. 3.1 Sectional view of the solar dryer

3.3.3 Operation of the dryer

The operation of dryer is an easy and friendly one. It is an active system in the sense that it has moving parts. It is energized by a fan powered by photovoltaic source assisted the airflow through the drying system in the collector glazing. The solar dryer also includes two 12 V, 3.3 A D.C.-fan attached to the intake of collector. The trapping of the rays is enhanced by the inside surfaces of the collector that were painted black and the trapped energy heats the air inside the collector. The effect achieved within the collector via a fan drives the air current through the drying chamber. If the vents are open, the hot air rises and escapes through the upper vent in the drying chamber while cooler air at ambient temperature enters through the lower vent in the collector. Therefore, an air current is maintained, as cooler air at a temperature enters through the lower vents and hot air at a temperature leaves through the upper vent.

When the dryer contains no items to be dried, the incoming air at a temperature 31.3^{0}C has relative humidity 50% and the out-going air at a temperature 29.5^{0}C, has a relative humidity Because 53% and the dryer contains no item. Thus there is tendency for the out-going hot air to pick more moisture within the dryer as a result of the difference between and therefore, insulation received is principally used in increasing the affinity of the air in the dryer to pick moisture.

3.3.4. Design calculations

3.3.4.1. Collector Efficiency

Collector efficiency measures the thermal performance, i.e. the useful energy gains of the collector. Not all of the solar radiation from the sun incident on the collector surface is converted to heat. Part of the radiation is reflected back to the sky and the other component is absorbed by the glazing. Once the collector absorbs heat and as a result temperature gets higher than the surrounding, there will also be a heat loss to the atmosphere by convection and radiation (Struckmann, 2008).

Collector efficiency, $\eta_c = \frac{VQ\Delta TC_p}{I_c A_c} x\ 100$ (3.2)

Where; V = Volumetric flow rate of air, m^3/s

Q = air density, kg/m^3

ΔT =Air temperature elevation, °C

C_p = air specific capacity, $J/kg°C$

I_C = Isolation on collector surface W/m^2

A_C = Collector area m^3

$$\eta_c = \frac{0.0126 \text{ x } 2 \text{ x } 30 \text{ x } 1005}{610.2 \text{ x } 1.78} \text{ x } 100$$

$$\frac{75978}{1086.156} = 70\%$$

3.3.4.2. Drying Efficiency

Drying efficiency is the ratio of the energy needed to evaporate moisture from the material to the heat supplied to the dryer. This term is used to measure the overall effectiveness of a drying system (Dhanushkodi *et al.*, 2014). But it may not be used for comparing one dryer with another due to different factors such as the particular material being dried, the air temperature and mode of air flow may differ for various dryers (Brenndorfe *et al.*, 1987).

$$\text{Drying Efficiency, } \eta_d = \frac{M_w L}{I_c A_c t} * 100 \tag{3.3}$$

M_w = weight of moisture evaporated = 0.85kg

L = Latent heat of evaporation of water (at temperature of dryer) = 2264 kJ/kg

t = drying period = 5days

Drying Efficiency, $n_d = \frac{0.85 \times 2264}{610.2 \times 1.78 \times 5} \times 100 = 35.4\%$

3.3.4.3. Drying Rate

Drying rate is the amount of evaporated moisture over time (Dhanushkodi *et al.*, 2014).

$$DR = \frac{M_i - M_d}{t} \tag{3.4}$$

M_i = mass of sample before drying =2kg

M_d = mass of sample after drying =1.15kg

t = drying period = 5days

$DR = \frac{2 - 1{,}15}{5} = \frac{0.85}{5} = 0.17$

3.3.4.4. Moisture Content

Moisture content is one of the important parameters that is taken to evaluate the performance of a dryer. Moisture content of a material can be given either on the basis of total weight of the material to be dried or the amount of solid weight present in the material. The moisture content on wet basis is given by the following equation (Fudholi*e t al.*, 2011):

$$MC(w.b),\% = \frac{w-d}{w} * 100 \tag{3.5}$$

w = weight of wet material =2000g

d = weight of dry material=1150g

MC (w.b), % = $\frac{2000-1150}{2000} \times 100 = 43\%$

Dry basis moisture content is given by (Mercer, 2007):

$$\text{MC (d.b.) g water / g dry solids} = \frac{w-d}{d} \tag{3.5a}$$

MC (d.b), % = $\frac{2000-1150}{1150} \times 100 = 73.9\%$

Nocturnal moisture re-absorption or loss, Rn, is the ratio of the increase in moisture content during the night period to the moisture content value at the sunset of the previous day. If the value of R_n is positive, it indicates moisture re-absorption, but negative value implies further moisture loss (Medugu, 2010).

$$R_n = \frac{M_{sr} - M_{ss}}{M_{ss}} * 100 \quad =14\% \tag{3.5b}$$

M_{sr} = moisture content at sunrise (%)

M_{ss} = moisture content at sunset (%)

M_{SR}= 0.85% and Mss= 0.97%

$$R_n = \frac{M_{sr} - M_{ss}}{M_{ss}} \times 100 = \frac{0.97 - 0.85}{0.85} \times 100 = 8.2\%$$

3.3.4.5. Sizing of the dryer chamber

The breadth of the drying chamber, B, is made equal to the width (W) of the air-heater. Thus, the length of the drying chamber, L_{dc}, is determined from the relation

$$L_{dc} = \frac{A_{dc}}{W} \tag{3.6}$$

$$L_{dc} = \frac{A_{dc}}{W} = \frac{0.7 \times 0.7}{0.7} = \frac{0.49}{0.7} = 0.7m$$

3.3.4.6. Average drying rate

Average drying rate, m_{dr}, would be determined from the mass of moisture to be removed by solar dryer and drying time by the following equation.

$$m_{dr} = \frac{m_w}{t_d} \tag{3.7}$$

$$m_{dr} = \frac{m_w}{t_d} = \frac{0.85}{9} = 0.094$$

3.3.4.7. Solar collector/ Air heater angle of tilt (β)

It states that the angle of tilt (β) of the air heater should be

$$\beta = 10^0 + Lat\ \phi \tag{3.8}$$

Where Lat ϕ is the latitude of the collector location, the latitude of Ikole-Ekiti where the dryer was designed is latitude 7.7983^0N, hence, the suitable value of β use for the collector:

$$\beta = 10^0 + 7.7983^0$$

$$\beta = 17.7983^0$$

3.3.4.8. Insulation on the collector surface area.

A research obtained that the value of isolation for Ikole – Ekiti i.e. average daily radiation H on horizontal surface as;

H = 600 W/m^2

And average effective ratio of solar energy on tilted surface to that on the horizontal surface R as;

R = 1.017

Thus, insulation on the collector surface was obtained as

$I_C = H_T = H_R = 600 \times 1.017 = 610.2$ W/ m^2 (3.9)

3.3.4.9. Determinations of collector Area and Dimension.

The mass flow rate of air M_a was determined by taken the average air speed V_a = 0.2 m/s

The air gap height was taken as 9cm = 0.09m and the width of the collection assumed to be 90 cm = 0.9 m

Thus, Volumetric flow rate of air

$V_a^i = V_a \times 0.09 \times 0.9$

$V_a^i = 0.2 \times 0.09 \times 0.9 = 0.0126 m^3/s$

Thus, mass flow rate of air

$$M_a = V_a P_a \quad (3.10)$$

Density of air ρ_a should be taken as 2 kg/m^3

$M_a = 0.0162 \times 2 = 0.0324$ kg/s

Therefore, area of the collector A_C

$$A_C = \frac{M_a\, C_p\, \Delta_T}{I_c W} \quad (3.11)$$

$$A_C = \frac{0.0324\ X\ 1005 \times 30}{610.2\ X\ 0.9} = \frac{976.86}{549.18}$$

$A_C = 1.78 m^2$

Length of the solar collector (L) was taken as;

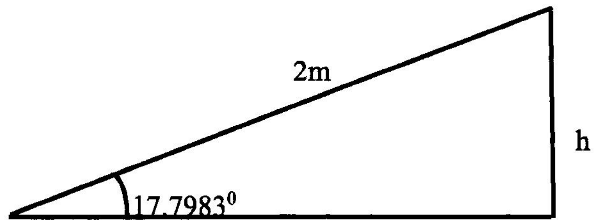
$$L = \frac{A_c}{B} = \frac{1.78}{0.9} = 2.0 \text{ m} \quad (3.12)$$

Therefore, collector area was taken as (2 x 0.9) = $1.8 m^2$

Vent area = Width of collector x Air gap height (3.13)

$= 0.9 \times 0.09 = 0.081 m^2$

3.3.4.10. Height of the solar collector



$$\sin\theta = \frac{H}{w} \qquad (3.14)$$

$$\sin 17.7983^0 = \frac{H}{2}$$

$$H = \sin 17.7983^0 \times 2$$

$$H = 0.61m$$

3.3.5 Backup Heater

The backup heater used bed rock as a source of energy. The bed rock was painted with black plaint to enhance the store of heat during the day time. For this project, the medium type of bed rock was used. It had a height of 25 cm and diameter of 10 cm. The heat from the bed rock used for drying was collected indirectly. The hot air from the bed rock escaped through a chimney which was connected at the top of the cover. At the top of the chimney was a cylindrical surface metal sheet cover.

3.3.5.1. Drawing of the Dryer

The dryer was designed using a software called AutoCAD. The drawing of the design and the corresponding side views with dimensions are shown in Figure 3.2 and Figure 3.3

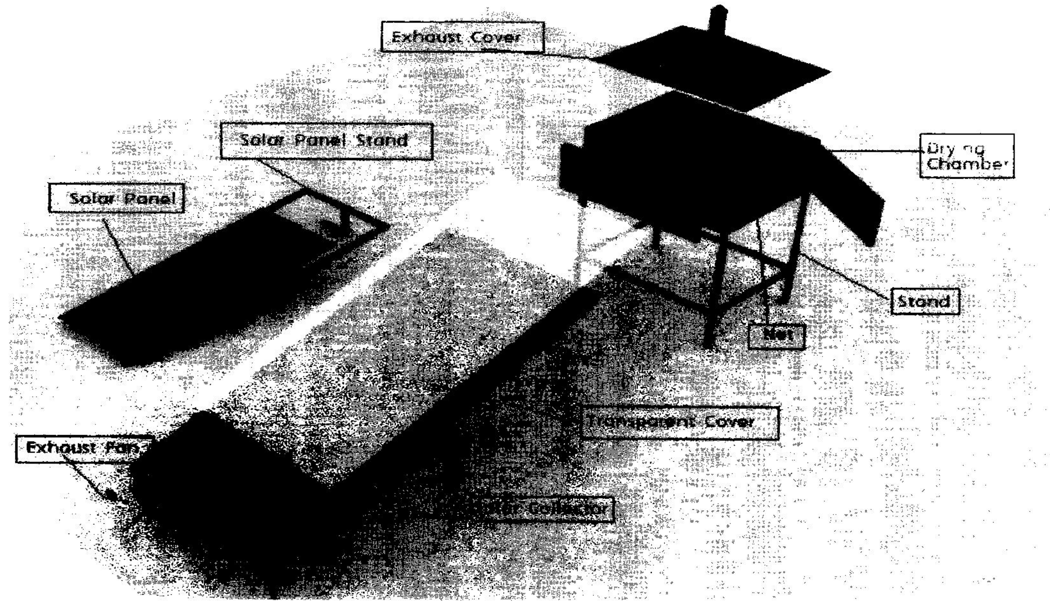


Fig. 3.2. Dryer drawing

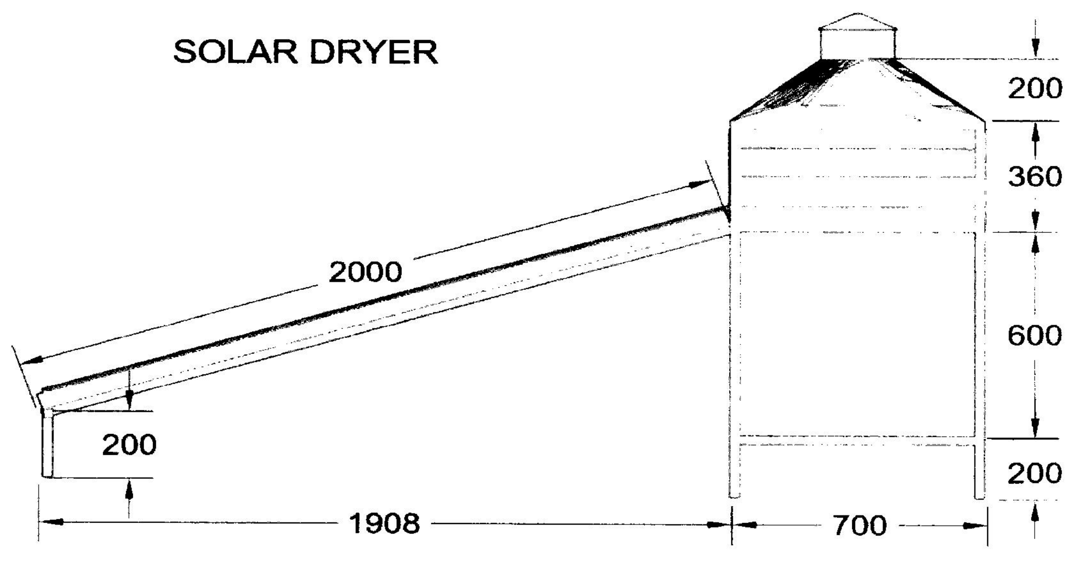


Fig. 3.3. Side view of the dryer

All dimensions are in mm

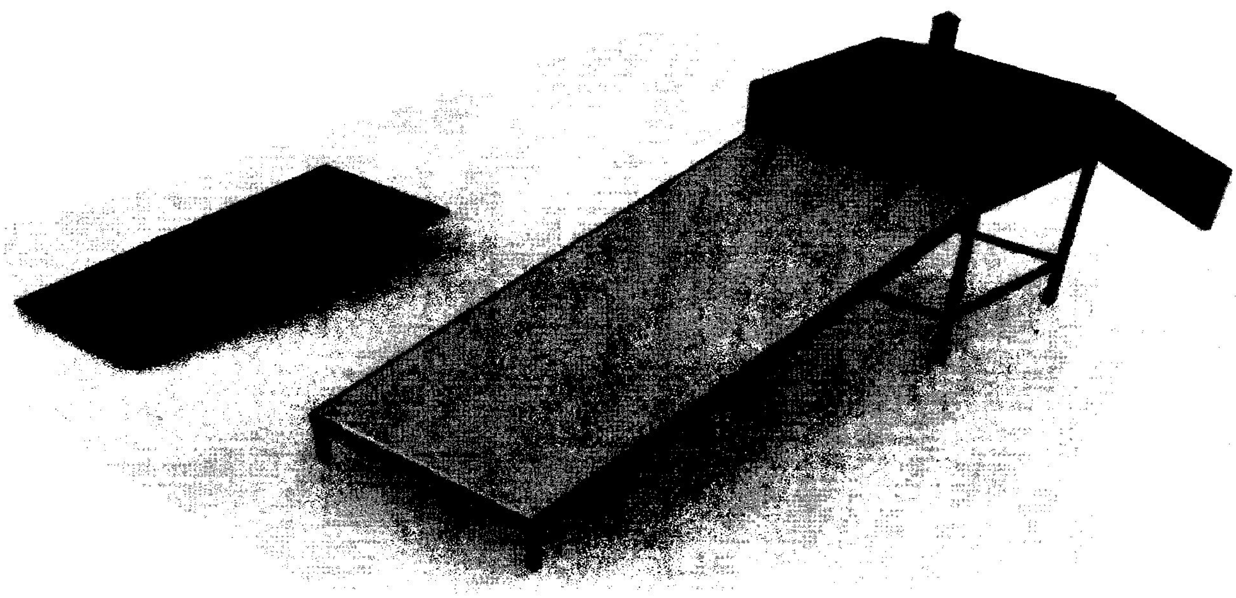


Fig 3.4. Pictorial view of the assembled locust bean dryer

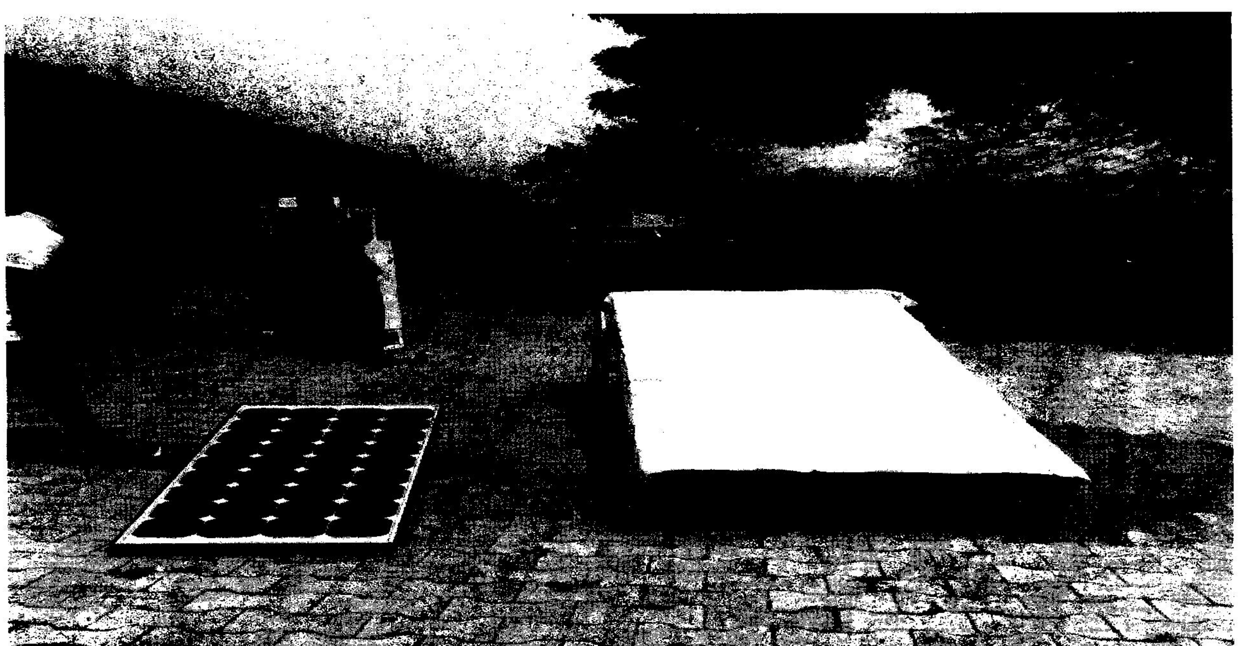


Fig. 3.5. Pictorial view of the constructed dryer.

3.4 General description of the solar dryer

The solar dryer comprises of three essential parts namely the fan, the solar collector and the drying trays. Each of these components has specific function it plays in order to ensure that the solar dryer functions appropriately. The solar collector tracks and receive the sun, the fan aids the movement of air into the drying chamber and the drying trays is the portion where the products to be dried are placed while drying.

3.5 Material selection

The performance of the solar dryer depends greatly on the choice of material for its construction. Material selection for the construction of the solar dryer has to be capable of satisfying a major desired function such as:

i. To be able to resist structural damage by strong wind and other stormy conditions in a fixed position, i.e the strength and the weight of the material used.

ii. The ability to sustain easy operation, maintenance and reconstruction.

iii. To ensure the material can be sourced locally, i.e the availability of the material

iv. The ability to resist corrosion

v. The cost of the materials used.

3.6 Safety measures and maintenance of the solar dryer

3.6.1 Safety measures

The safety measures when operating the solar dryer are as follows:

1. The operator of the solar dryer must protect the eyes from sun glares.

2. When operating the dryer, the operator has to stand beside the dryer in order not to intercept the incoming sun rays.

3. The drying trays placed inside the drying chambers should not be too large in order to minimize loss.

4. Children should not be allowed near the dryer when in use.

3.7 Maintenance for efficiency performance

For efficient performance of the oven, the following maintenance culture is necessary. They are;

1. Ensure regular cleaning of the surface of the solar concentrator before using it in order to keep its sun ray absorbing surface shinny for excellent sun reflection.
2. Ensure regular cleaning of the drying trays after using it in order to keep them from contaminating the food produce.
3. Ensure regular check of the dryer so as to replace any worn out part of the dryer.

BILL OF ENGINEERING MEASUREMENT AND EVALUATION (BEME)

S/N	NAME OF PART	MATERIALS AND DIMENSION	QUALITY	UNIT PRICE	AMOUNT
1	Metal Sheet	Metal Sheet 0.5mm,1.2mm	2	18000	36000
2	Flat bar	Flat bar 1 inch	9	2200	19800
3	Angle iron	Angle iron 1 inch	8	1700	14600
4	Square pipe	Square pipe 1 inch	2	2200	4400
5	Riveting pin	Riveting pin	1	2700	2700
6	Wire mesh	30×90	3	900	2700
7	Metal rod	$10mm^{18ft}$	1	1800	1800
8	Solar panel		1	18000	18000
9	Electrode	Oelkon 250×350	2	6000	12000
10	Cutting disc	$9 \times 5/64'' \, {}^{7}/_{8}$	2	5000	10000
11	Grinding disc	$9'' \times$ [illegible]$'' \times {}^{7}/_{8}''$	2	5000	10000
12	Nylon		1	1500	1500
13	Black tube		4	2000	8000
14	Fan	12V, 3.3DC	2	6000	12000
15	Filler		1	2000	2000
16	Gum	Resin	4	500	2000
17	Black paint		10	700	7000
18	Miscellaneous			23800	23800
		TOTAL			# 188,300.00

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Presentation of Results

The solar dryer was used to conduct series of drying operations in other to evaluate the performance level. Certain quantities of food items were dried using the solar dryer. The experiment took place at FOUYE in the month of March, 2019. The preliminary test analyses carried out on the solar dryer, which were subjected to different climate condition over time.

The objectives of the test analyses carried out were to achieve the following:

1. Promote uniformity and consistency in the terms and units used to describe, test, rate and evaluate the solar dryer, component and the dryer operation.
2. Provide a common format for presentation and interpretation of the test result to facilitate communication.
3. Provide unified measure of performance that consumers may use in evaluating different design when selecting a solar dryer.

4.2 Test Procedure

The procedures taken during the experiment are as follows

- ☐ The solar dryer were assembled in an open place for five consecutive days at Federal University Oye-Ekiti, Ekiti State. (FUOYE)
- ☐ The solar dryer was set to face the east in the morning
- ☐ The altitude angle was set
- ☐ The food samples were weighed on a weighing balance
- ☐ Ambient temperature and food content temperature measurement is recorded every one hour.

4.3 Drying Test for Locust bean

The Locust bean drying test was conducted on 4th of March 2019 with the solar dryer set in an open place at FUOYE ensuring that there is no obstacle intercepting the incoming sun rays. The locust bean was weighed before and after drying in the solar dryer. The temperature was determined by measuring the locust beans temperature every one hour. The moisture content was determined by measuring the weight of the locust bean every one hour.

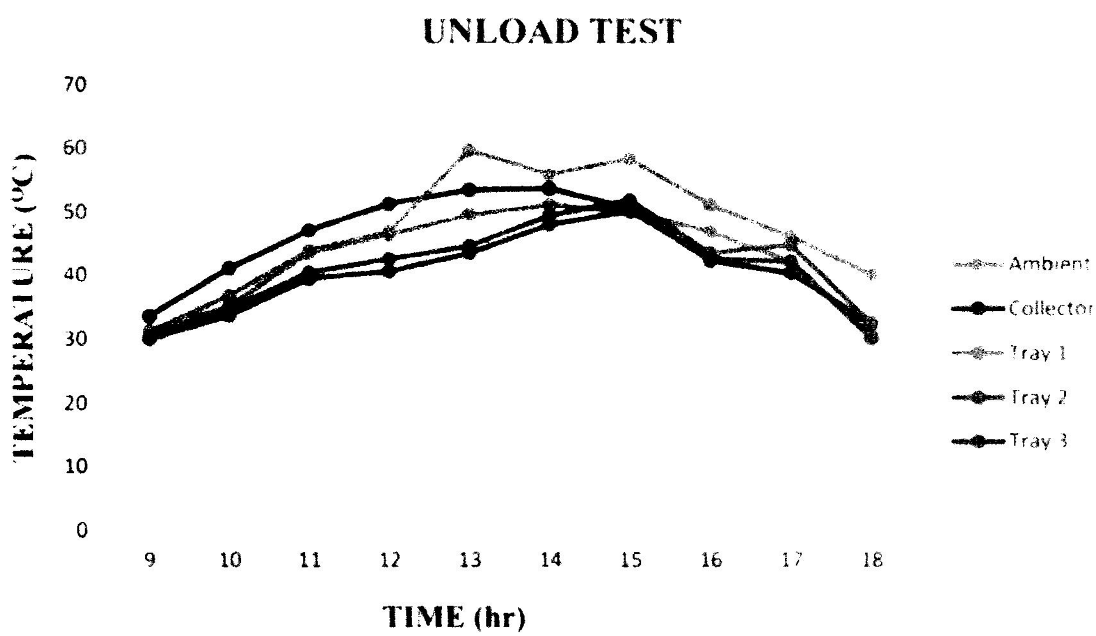


Fig. 4.1. Temperature variation with time for no load test.

During the day time when the sun was the only source of heat supply, a maximum temperature of 53.7°C was attained by the collector output after nine hours while the average collector temperature from 09:00 to 18:00 hour was 40.4°C. The collector reached its peak temperature value when the ambient temperature was 51.1°C. The maximum average temperature rise on the trays was about 58.3°C. This indicates that the maximum rise in temperature of the dryer was about 7.2°C more as compared with the ambient temperature. A similar no-load indirect type dryer test performed by Alonge and Adeboye (2012) resulted in a maximum temperature elevation of 48°C when the ambient temperature was 39°C. In addition, a higher drying chamber was reported by (Bolaji, 2005) who designed a box type indirect crop dryer where the maximum average temperature obtained in the drying chamber was 57.0°C, while the ambient temperature was 33.5°C.

The experimental performance for unloading the solar dryer with food and loading of the solar dryer with locust bean are shown in figure 4.1 and 4.2 respectively. From the results, it is revealed that the factors that determined the performance of the solar dryer includes; wind speed, amount of solar radiation and the time of the day.

1. Time of the day: The time of the day determines the amount of solar radiation the reflector tracks. Solar radiation is highest when the hour angle is 0° i.e at solar noon.
2. Wind speed: High wind speed generally decreases the performance of concentrating solar oven because it generates dust particles that covers the surface of the solar dryer and as well offsets of the solar dryer from the focal point.
3. Amount of solar radiation: The greater the amount of solar radiation received at a given period of time, the greater the performance of concentrating solar dryer.

4.4. Solar Drying Test

The moisture loss with time for locust bean seed, when the sun was used as the only source of heat supply, is shown in Fig. 4.2 and 4.3.

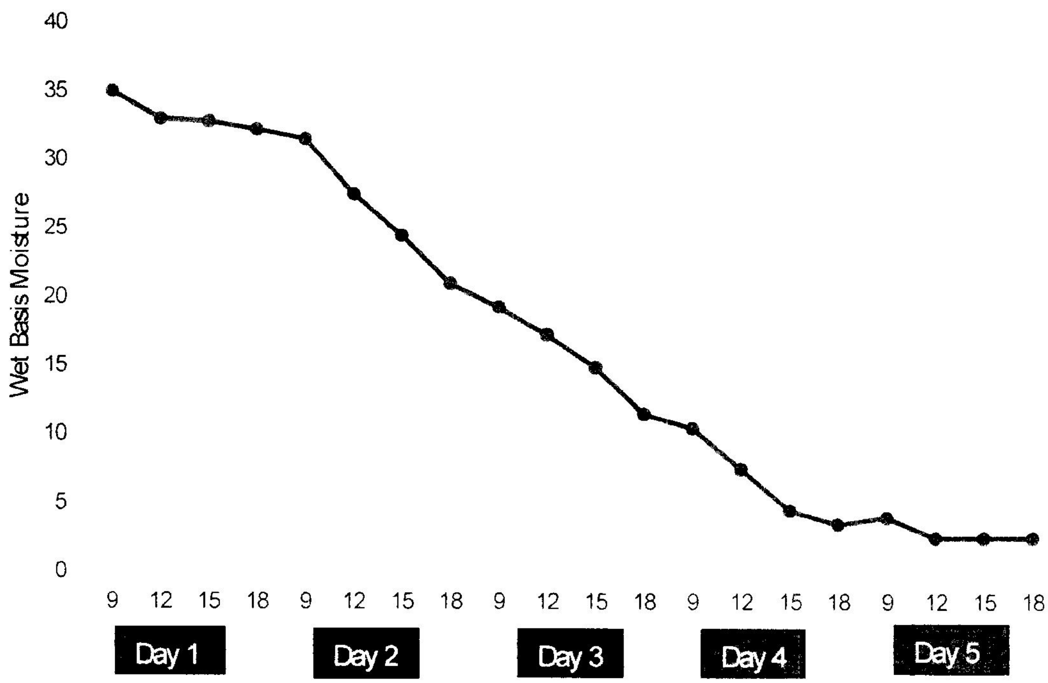


Fig. 4.2. Moisture loss (wet basis) for locust bean with time

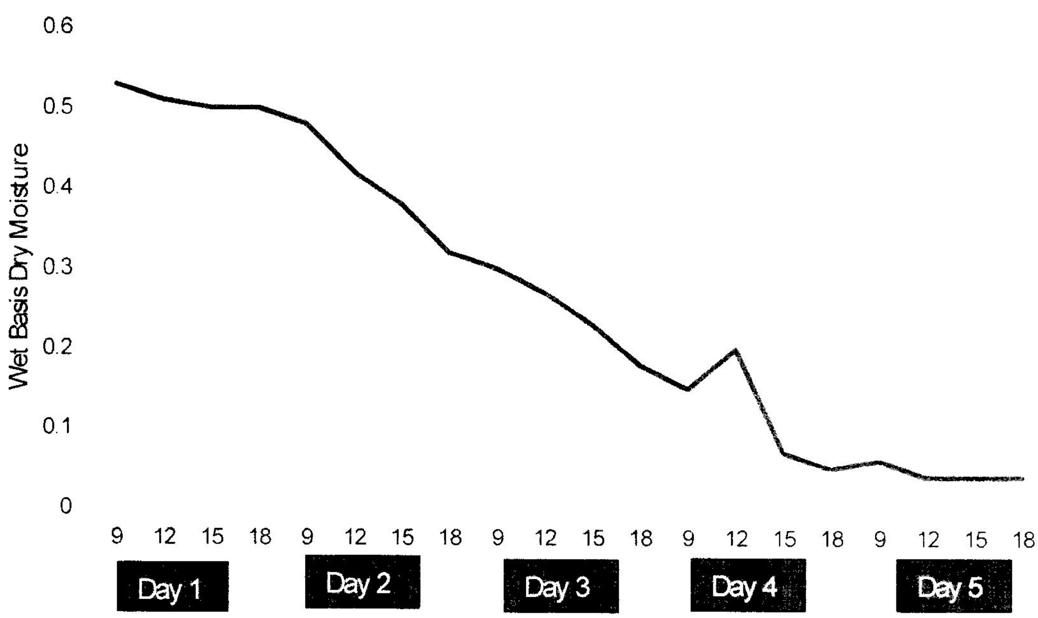


Fig. 4.3. Moisture loss (dry basis) for locust bean with time

As the inlet air passes through the collector and enters the dryer, it will have higher temperature and lower humidity. As the hot air rises in the drying chamber, it picks up moisture from the locust beans kept on the trays. This results in reduction of weight or moisture loss of the locust bean. The moisture content of locust beans was reduced from 35 % (w.b.) to 2.5 % (w.b.) or 0.53 g H_2O/g solids (d.b.) to 0.04 g H_2O/g solids (d.b) within five days.

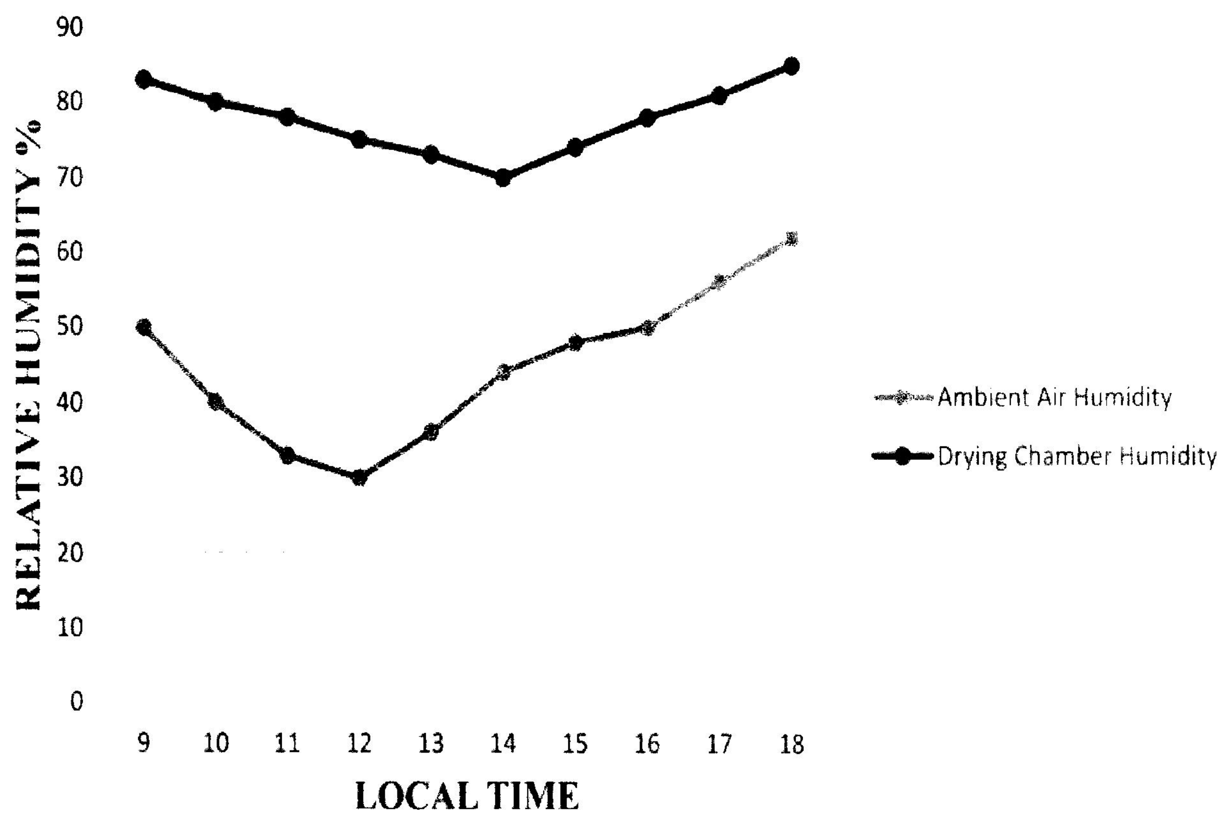


Fig 4.4. Variation of the relative humidity of the ambient air and drying chamber

Fig 4.4. Shows the diurnal variation of the relative humidity of the ambient air and drying chamber. Comparison of this figure with Fig. 3 shows that the drying processes were enhanced by the heated air at very low humidity.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

In Nigeria, the potential of using solar for drying is high. The solar dryer was able to dry food products such as locust bean. The study reinforced the views that solar devices can play a major role in solving Nigerian's domestic energy problem especially in the rural areas rather than being a novelty demonstration of solar energy use. An indirect type solar dryer with a photovoltaic (PV) solar panel to power the fans and backup heater was designed and constructed with materials readily available in the market which had a storage energy system was developed, to study the drying behavior of locust bean. The dryer is easy to operate and handle. An additional system, backup heater consisting of a bed rock, was included in order to make drying continuous throughout the night and cloudy periods. Under no-load condition, the average collector temperature reached 56.4^{0}C and that of the dryer reached 45.1°C while the average ambient temperature was 34.6°C.When only the backup heater was used in the evening by bed rock a temperature as high as 50.8°C was recorded on the bottom tray. This indicated that the temperature in the dryer was raised above the ambient temperature creating a suitable condition for drying.

The performance of the dryer was evaluated using locust bean in which the initial moisture contents were reduced from 95 % and 85 %, respectively, within two to three days. A better dryer performance in terms of drying rate was obtained when the dryer was operated in a hybrid mode, i.e. when heat was supplied by bed rock as a backup system. As a result, drying rate increased by 2.9 % (locust bean) than the drying rate in solar dryer.

The collector efficiency obtained from no load test was 31.5 %. This value is well in the range recommended by different literature for natural convection solar dryers. The drying efficiencies were 9.7 %, 8.7 % and 7.5 % for solar drying, backup heater used throughout the drying period and backup heater used only in the evening.

It was found that the solar dryer can dry high initial moisture content fruits such as locust bean to the recommended value of moisture content for safe storage within two to three days. The solar dryer can be used during any time and season as a result of the heat provided using the backup bed rock. Hence, it can provide a means of preserving agricultural produce that are harvested in the rainy season.

5.2. Recommendations

The performance of the dryer can further be enhanced by making modifications and following the recommendations given below:

1. The gap between the collector and drying chamber should be covered with permanent insulation that can withstand rain.
2. There is need for the use of experimental design analysis for better performance evaluation and result analysis.
3. Insulating the drying chamber will help to attain a higher drying temperature, especially at night when the solar panel is the only source of heat supply.
4. Automatic controller could be introduced so as to ease the performance of the dryer.
5. Design modifications are required to maintain the same amount of drying temperature in the dryer when the bed rock is used. One such suggestion would be to internally extend the metal tube to the adjacent sides of the drying chamber. This would help to minimize the non-uniformity of heat transfer on a tray.

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APPENDIX 1

Typical temperature variation with time during unloading test

			Dryer Temperature ^0C		
Hour	Ambient Temperature	Collector temperature	Tray 1 Top	Tray 2 Middle	Tray 3 Bottom
9.00	31.3	33.6	31.2	30.2	30.0
10.00	35.1	41.1	36.8	34.7	33.7
11.00	43.6	47.1	44.0	40.5	39.5
12.00	46.4	51.3	46.9	42.6	40.6
13.00	49.5	53.5	59.9	44.7	43.5
14.00	51.1	53.7	55.9	49.4	48.0
15.00	s50.1	50.6	58.3	51.9	50.1
16.00	46.9	42.3	51.2	43.6	42.7
17.00	42.3	40.4	46.1	44.9	42.2
18.00	30.5	32.3	40.2	32.5	30.1

APPENDIX 2

Typical humidity variation with time during unloading test

Time	Ambient Air Humidity	Drying Chamber Humidity
9.00	50	83
10.00	40	80
11.00	33	78
12.00	30	75
13.00	36	73
14.00	44	70
15.00	48	74
16.00	50	78
17.00	56	81
18.00	62	85

APPENDIX 3

Sample Analysis of Moisture Content

Day	Time	Sunshine hour	Locust bean weight (g)	Solid weight (g)	Moisture weight (g)	Wet basis moisture	Dry basis moisture g/H_20/g Solid
Day 1	9:00	0	2000	1300	700	35.0	0.53
	12:00	3	1960	1300	660	33.0	0.51
	15:00	6	1955	1300	655	32.8	0.50
	18:00	9	1945	1300	645	32.3	0.50
Day 2	9:00	0	1930	1300	630	31.5	0.48
	12:00	3	1850	1300	550	27.5	0.42
	15:00	6	1790	1300	490	24.5	0.38
	18:00	9	1720	1300	420	21.0	0.32
Day 3	9:00	0	1685	1300	385	19.3	0.30
	12:00	3	1645	1300	345	17.3	0.27
	15:00	6	1598	1300	298	14.9	0.23
	18:00	9	1530	1300	230	11.5	0.18
Day 4	9:00	0	1500	1300	200	10.5	0.15
	12:00	3	1450	1300	150	7.5	0.20
	15:00	6	1390	1300	90	4.5	0.07
	18:00	9	1370	1300	70	3.5	0.05
Day 5	9:00	0	1380	1300	80	4.0	0.06
	12:00	3	1350	1300	50	2.5	0.04
	15:00	6	1350	1300	50	2.5	0.04
	18:00	9	1350	1300	50	2.5	0.04