

CHAPTER ONE

INTRODUCTION

1.1 Background

Wood is a natural versatile and variable material. There is an urgent need to recognize the virtues and develop means of protecting and rationalizing the use of such a valuable resource. Winger,(1977) stated that When used for construction, furniture millwork and other similar uses wood will perform better if it is dried prior to use to the equilibrium m.c.

As wood comes from the tree it contains appreciable amount of water frequently as much as 100 – 200 per cent in terms of its oven-dry weight. Wood begins to lose moisture as soon as it is exposed to atmospheric conditions. As wood dries below the fiber saturation point it shrinks. The shrinkage is not equal in all directions. This inequality in shrinkage in three directions at right angles to one another sets up strains which are unavoidable and which may cause fracture in the wood tissues (Panshin and de Zeeuw, 1980). For many end uses, wood must be formally dried under control to perform satisfactorily. If formal drying is not carried out before the final product is made under controlled drying will occur in service, often with disastrous results. Wood is dried in a variety of shapes and sizes. The appropriate drying technique depends on size and species. Because there are thousands of tree species or generic groups in the world with some commercial importance , we are faced with formidable range of possible drying techniques.

Nasroun,(1979) reported that Observations made at different timber depots in Sudan as well as sawmills, showed that splitting and distortion of timber, resulting from uncontrolled drying, are among the major causes of timber losses and failures if not the major ones. This is due to two main reasons: lack of proper drying and the hot dry conditions prevailing in many parts of Sudan. Proper wood drying is, therefore, an essential process in nearly all wood utilization practices. This means that timber must be dried to the proper moisture content for end- use requirements. This is essential because the inherent value of timber and its potential commercial uses are generally affected

by the nature and magnitude of the defects that occur during drying. This is why timber markets are demanding greater emphasis on improved quality of timber drying and in-service moisture content.

Wood drying, however, is the most energy intensive of all wood Manufacturing processes. Water is removed from wood by Supplying a large amount of thermal energy. The different drying methods differ from one another by the source and method of supplying this energy. Air (or natural) drying is simple and not costly, but it takes a long time and dries timber to the equilibrium moisture content only. Kiln drying, on the other hand, is faster and dries wood to any moisture content desired, but it is very expensive to install and operate and requires skilled operators. Solar drying is expected to be in the middle and have most of the advantages of the two traditional methods mentioned above. So solar energy applications began to look more attractive in the past decades (Simpson and Techernitz, 1977).

Solar dryers should improve drying conditions because the temperature available for drying is raised above ambient temperature, air circulation is sustained over the drying period and some control is exercised over the relative humidity (Troxell, 1977) .If solar drying reduces drying time over that of air drying and if drying defects are within acceptable limits, then this will be a great achievement, since only the sun will provide all the energy required. When compared with conventional steam or direct-fired drying kiln solar drying shows significant savings in capital and operating costs, but longer drying time is required. Fortunately experience and certain generalities make the choice easier (Simpson, 1983). The different drying methods differ from one another by the source and the methods of supplying the required thermal energy. Solar energy applications began to look more attractive in the past decades (Simpson and Tschernite,1977). It is somewhere in the middle between traditional air drying and Kiln drying with regards to rate of drying and costs. The two conventional methods- air drying and Kiln drying are the most widely used throughout the

world. Air drying is the most economical practice in hot dry conditions like Sudan. This method uses the heat carried by the natural air current for drying the timber stack. It is therefore cheaper, but takes a long time. Drying Kilns are chambers of special type with adequate source of thermal energy and sophisticated control devices for controlling temperature, relative humidity and air circulation at every location inside the Kiln. All this indicates that drying Kilns are expensive to buy, install and operate. (Nasroun and Shommo 1983) .

1.2 Research Problem:-

Because of the great values in wood, there is urgent need to recognize these virtues and develop means of protecting and rationalizing the use of this valuable resource. Splitting and distortion of wood due to lack of proper drying are the major causes of timber losses and failure. Many locally grown hardwoods are particularly susceptible to these defects. Proper wood drying is therefore an essential processes to nearly all wood utilization practices. Wood drying, however, is the most energy intensive of all wood manufacturing processes. Air (natural) drying is simple and cheap, but it takes a long time and dries timber to equilibrium moisture content only. Kiln drying, on the other hand, is faster and dries wood to any moisture content but it is very expensive to install and operate and requires skilled operators. Solar drying is expected to be in the middle and have most of the advantages of the two traditional methods mentioned above. The aim of this investigation is therefore to search for a relatively simple, cost effective and energy- efficient solar dryers which will speed up air drying with minimum wood degradation.

1.3 Specific Objectives:

1. To compare the performance of two designs of solar dryers with that of traditional air drying with regards to reducing drying time and drying defects in *Acacia nilotica*.

2. To assess the response of *Acacia nilotica* to air drying and solar drying with the aim of finding a suitable drying schedule for this species.

3. To assess the feasibility of such solar dryer and the potentiality of using it economically and efficiently in the major Forest national Corporation sawmills.

Expected outcome:

*Energy Conservation.

*Prevention of Shrinkage, distortion and splitting of wood in service.

*Supply of sound wood material for furniture and building construction.

CHAPTER TWO

LITERATURE REVIEW

2.1 General:

Wood contains water in two forms: free water and bound water. Free water represents the bulk of water contained in the cell lumina held by capillary forces only. Free water is not at the same thermodynamic state as liquid water. Energy is required to overcome the capillary forces. Bound water, on the other hand, is bound to the wood by hydrogen bonds. The attraction of wood to water to water arises from the presence of free hydroxyl (OH) groups in the cellulose, hemicelluloses and lignin molecules in the cell walls. The hydroxyl groups are negatively charged electrically. Water is a polar liquid. The free hydroxyl in the cellulose attract and hold water by hydrogen bonding (Siau, 1984).

As the definition of wood moisture content implies, the basic method for measuring moisture content is gravimetric, but there are many - up to fifteen - methods which have been used. In the basic gravimetric method of measuring wood moisture content the moist sample is weighed and then oven dried until the reference weight W_0 is attained. For ordinary moisture content determination, where high precision is not required, the dry weight W_0 is obtained simply by drying the sample in an oven maintained at $103 \pm 2^\circ\text{C}$ until constant weight is attained. This procedure reduces the sample moisture content to a low value at equilibrium with a relative vapor pressure sufficiently close to zero that the sample is assumed to have attained its dry weight W_0 . The evaporation of volatile components other than water during drying may cause substantial error in the gravimetric method of measuring moisture in wood. In this case it is necessary to use a modification of the gravimetric method by heating the wood in a distillation apparatus containing a water-immiscible liquid which is a solvent for the volatile extractive compound. Most methods for measuring wood moisture content destroy the sample to be tested and require

long time to obtain meaningful measurements . However, the development of electrical method for measuring wood moisture content has made it possible to sample the moisture content of wood nondestructively and almost instantaneously. (skaar, 1972). Wood containing moisture exerts a vapor pressure the magnitude of which depends on its moisture content and temperature . With green wood the vapor pressure it exerts is equal to (or very nearly equal to) that exerted by pure water at the same temperature . As the moisture content of wood falls , the vapor pressure it exerts decreases , only very slowly down to the fiber saturation point , but rapidly below that point . A piece of green wood exposed to the atmosphere will dry by evaporation from its surface provided that the atmosphere is not already saturated with water vapor. The rate of drying will depend on the difference between the vapor pressure exerted by wood and that of the atmosphere, and will decrease as the moisture content of the wood falls. Drying will cease when the vapor pressure exerted by the wood become equal to that of the atmosphere , and the moisture content at this stage is referred to as the equilibrium moisture content (EMC) corresponding with the prevailing atmospheric conditions of temperature and humidity (FPRL, 1969).

Wood is a hygroscopic material. because of this it loses liquid water and water vapor when is it exposed to a surrounding medium in which the relative vapor pressure is less than that within the wood itself . Water absorption takes place when the conditions are reversed. This exchange of moisture between the wood and the surrounding medium continues until a state of balance called the equilibrium moisture content is reached. The rate at which moisture moves in the wood depends on

- 1- The Relative Humidity of the surrounding air,
- 2- The steepness of moisture gradient,
- 3- The temperature of wood.

Of these, relative humidity and the difference between the relative vapor pressure of the air and that in the wood is of utmost importance. Low relative humidity increases the capillary flow of moisture from the wood and stimulates

diffusion of water by lowering the moisture content at the surface. This results in steepening of the moisture gradient from the surface to the interior of the piece, accompanied by development of stresses traceable to the strains arising from dimensional changes. The drying stresses in wood could be classified into three orders on the basis of the scale on which these stresses operate, The first order stresses occur in the individual cells because of the unequal shrinkage potential of the cell wall layers and hydrostatic tension in the cell cavities . The second order stresses occur from unequal shrinkage potential of the various tissues in the wood. The third order stresses occur in larger pieces of wood as a result of the moisture gradient that develops in normal drying and from the gross anisotropic nature of wood (Pashin and Dezeeuw, 1980)

2.2 Methods of Drying Timber:

Broadly, there are two methods by which timber can be dried:

(i) natural drying or air drying, and (ii) artificial drying, or kiln drying.

2,2.1.Air drying:

Wood can be dried in many ways and in nearly all of them the moisture is extracted in the form of water vapor. When the moisture leaves as vapor, heat must be supplied to the wood to provide the latent heat of evaporation. In point of fact nearly all the world's timber is at present air dried, using the term in its broadest sense to indicate that air is the medium used for conveying heat to the wood and for carrying away the evaporated moisture. Air drying in the narrower sense meaning that the timber is allowed to dry in the open or in sheds without any artificial heating or air movement (FBRL, 1969).

In a hot dry country like the Sudan air – drying is the most economical practice. This method uses the thermal heat carried by the natural air current for drying the stacked lumber, therefore it relies completely on environmental conditions. There are, however, certain restrictions and precautions which must be taken to avoid any distortion or seasoning degrade. In

order to economize in space the timber must be piled; and a variety of stacking configurations are used to air-dry wood. Timber should be stacked under a shed which is made on a carefully selected, well drained, clean site. The bearers which carry the timber stacks should be raised from the ground by means of concrete piers to ensure free circulation of air. For the same reason the stacks should be of reasonable width and height. The height of the piles is limited only by the ease of piling. The layers of the stack should be separated by stickers at reasonable distances and the stickers should be in line with the bearers. Heavy weights are required on the top of the stack to avoid any twisting or bowing. . Air-drying is cheaper than other methods, and if it is used prior to kiln drying it will result in large energy saving. Air drying, however, takes a longer time especially in cool humid areas. It dries timber down to the equilibrium moisture content and not lower than this (Nasroun, 1979).

2.2.2.Kiln drying:

Kiln drying is carried out in a closed chamber, providing maximum control of air circulation, humidity, and temperature. In consequence, drying can be regulated so that shrinkage occurs with the minimum of degrade, and lower moisture contents can be reached than are possible with air seasoning. The great advantages of kiln seasoning are its rapidity, adaptability, and precision. It also ensures a dependable supply of seasoned timber at any season of the year, and it's the only way that timber can be conditioned for interior use requiring lower equilibrium moisture contents than those prevailing out doors, or in unheated sheds.

In properly operated kilns variation in moisture content across the section of a plank and differences from plank to plank within a load can be kept low. It is necessary to regulate kiln drying to suit circumstances: different timbers and dimensions of stock require drying at different rates. As a general rule, soft woods can withstand more drastic drying conditions than hardwoods,

thin board better than thick planks and partially dried stock better than green timber. (Koch 1972).

The characteristics of an ideal drying kiln can be summarized in the following:-

- 1- Availability of a thermal energy source and a method of transfer to the wood.
- 2- Ability to control temperature, relative humidity and air speed at every location in the kiln.
- 3- Ability to monitor stresses (or shrinkage) and regulate the total drying process on the basis of stress development.
- 4- Capacity to dry large volumes of wood.

With the existing technological standards, and the scarcity of technical know-how and for economic reasons, its very unlikely that kiln drying will be considered on a large commercial scale in the near future. This, in addition to the fact that the climatic conditions in central and northern Sudan (major consumption centers), with high atmospheric temperature and low relative humidity are favorable for air drying which is more economical. (Nasroun, 1979).

2.2.3.Kiln drying schedules:

Schedules giving the temperature and relative humidity conditions considered appropriate at various stages of a kiln-drying process have been published by many authorities for a wide range of wood species and thickness. Without question these have been of considerable help to kiln operators, especially to those called upon to dry a timber with which they have had little or no experience. It is widely recognized, however, by those responsible for publishing the schedules, that there are many factors which ought to be taken into account when deciding on the most suitable treatment for a particular kiln load and that schedules should be modified accordingly. (FBRL,1969). These drying schedules prescribe the environmental conditions inside the kiln while timber is being dried. The drying schedules are (recipes) determined by experience through trial and error. The schedules consist of

rules for making changes in temperature and relative humidity of the kiln (Nasroun , 1979) .

A drying schedules is a compromise between the desire to dry wood as rapidly as possible yet slowly enough to avoid drying defects (Rosen and Bodkin , 1981) .

2.2.4.Solar drying :-

Interest in solar drying lumber dates back to many years , but the energy crisis of the early 1970^s brought on a flurry of activity . Most of the activity confined to designing and testing of small experimental dryers, with only a few in commercial use . The proposed design, both greenhouse and external collectors types have usually been intended as low – cost dryers, often for use by small producers or in tropical developing countries . With only a few exceptions , the design incorporate flat – plate collectors with air as the heat transfer medium. Typical temperatures realized in solar kilns usually range from 15-20⁵c above ambient , with maximum temperature of from 50-60⁵ c. Controls have usually been crude or non existent , but there has been a recent trend to provide some control through low – cost humidistat's , thermostats humidifiers, etc. (Simpson, 1983) Solar kilns of various designs were developed by research agencies in several countries. The result of these trails and developments were evaluated with the object of arriving at the most economical and the most energy efficient designs. Although there are some differences in design details , most solar kilns feature the same general construction, they are

mostly of wood-frame construction covered with one or more transparent or translucent plastic or fiberglass sheets . This cover is necessary for trapping the heat that is absorbed and preventing its re-radiation into the atmosphere . Where two sheets are used , one outside and one inside – the framing , an insulating air space will be provided between the two sheets . In designing solar kilns or dryers , the intent is to provide all the functions of conventional dry kiln at minimum cost (Nasroun and Shommo 1983) . Many studies all over the world indicated that solar dryers are more effective than air drying with respect to reducing drying time. In most cases the solar dried timber had fewer drying defects than matched lumber specimens which were air dried. Significant savings in operating costs over conventional kilns were noted. Solar drying defects are usually within acceptable bounds and drying time falls between that of air drying and the kiln seasoning (Nasroun ,1979). The reduction in drying time for hardwoods provides a reduction in energy and labor cost . The reduction in drying defects can increase yield. A semi – greenhouse solar dryer was used in Egypt to dry Casuarina wood .The result confirmed the advantages of solar drying in comparison with traditional air drying (Helwa *et al*, 2004). Bekkioui ,*et al* (2011) concluded that a period of 17 days is necessary to dry pine wood in solar dryer from 35% to 10% moisture content .

2.2.5.Other Methods

A -Boiling methods

By the term boiling methods is meant such treatments as cause the moisture in wood to reach the boiling point and so to exert an absolute pressure which is greater than that of the surrounding atmosphere. An absolute pressure difference is set up and if there is no resistance to evaporation the rate of evaporation is determined by the rate of ingress of heat as in the boiling of a kettle .

Radio frequency is one such methods which proves to be most spectacular when the generated steam can pass out freely from the ends of a permeable wood such as beech. Unfortunately it is an expensive process and impermeable wood such as oak tend to shatter as the internal steam pressure rises. With permeable wood it may be ideal.

Another method is to place the wood in boiling oil but the moisture gradients set up normally becomes severe enough to split the wood . Furthermore the wood tends to absorb quantities of oil which usually is most undesirable. The next to be mentioned is the so-called vapor drying process. Here the wood, normally poles and sleepers are place in a cylinder and on to them are directed jets of heated xylene and similar vapors. Drying tend to be rapid but splitting is likely to occur. It is a complicated process , expensive and involves a fire hazard .

B; vacuum drying :-

The main difficulty to be overcome when drying at reduced pressures is concerned with the transmission of heat to the load . Without a supply of heat the moisture in the timber remains there in liquid form lacking as it would the latent heat required for evaporation . One method suggested was to heat the wood first in boiling water or steam and then to draw a vacuum rapidly and at the same time drain wall water and condensate from around the charge . The residual heat in the wood then causes the moisture in it to boil at the reduced pressures and a certain amount will evaporate and be removed . Soon, however

all this heat is exhausted and the vacuum needs to be broken and a fresh supply of boiling water or steam introduced . These cycles get less and less effective as the amount of wetting by the water or steam in the first phase tends to balance out the evaporation of moisture from the wood in the second .Such methods have been tried out many times but are now universally abandoned as being impracticable , expensive and ineffective .

C; Diffusion drying ;-

In the more orthodox form of drying such as air drying and kiln drying the moisture is caused to move under an imposed vapor pressure gradient is distinct from an absolute pressure gradient . A vapor pressure gradient is established when the surfaces of a piece of wood are at a lower moisture content than the interior or when two faces are at the same moisture content but one is hotter than the other . It would obviously be advantageous to arrange not only for the surfaces to be drier than the core but at the same time for the centre to be hotter than the outsides in order to achieve the maximum vapor pressure gradient consistent with the maximum permissible internal stressing .

D. Chemical drying ;-

Seasoning with the aid of chemical treatments has been undertaken and the modus operandi generally is to soak or spray the wood in or with hygroscopic liquids . Saturated solution of urea or common salts are often used and these are permitted to diffuse into the surface layer .

E. Mechanical drying ;-

Mechanical methods of drying have been attempted and for example drying by centrifuging was once in fashion . By the very rapid rotation of a very green soft wood some free moisture may be extracted but no hygroscopic or bound moisture could be caused to move by such means (FPRL,1969) .

2.3 Wood Drying Theories

Water can exist in three general states or phases – solid (ice) liquid or vapor ,depending upon the temperature and pressure to which it is exposed . It can exist in each phase only when the temperature and pressure are within the limits suitable for each phase . At equilibrium two phases can exist only . At the triple point , all three phases may exists simultaneously (Skaar , 1972). Wood drying includes three mechanisms of moisture movement that occur in various combinations and proportions , depending on species , thickness , and the stage of a drying .

- 1- Mass flow of liquid water through the capillary structure of cell cavities and inter-connecting pits occur of moisture content above fiber saturation point (FSP) .
- 2- Below FSP , diffusion of water occur through the net work of cell walls and cell cavities .
- 3- Removal of the water from the surface of wood.

The flow of free water above the FSP requires both a continuous passageway for flow and a driving pressure. The continuous passageway is provided mainly by cell cavities and interconnecting pits. The driving pressure is the difference between the pressure in the gas phase and the liquid phase (Simpson,1983). Water in wood normally moves from zones of higher to zones of lower moisture content .

Drying starts from the exterior of the wood and moves towards the centre, and drying at the outside is also necessary to expel moisture from inner zones of the wood (Langrish and Walker ,1993). The driving force of moisture movement is a chemical potential. However, it is not always easy to relate chemical potential in wood to commonly observable variables , such as temperature and moisture content (keyy etal, 2000). Moisture in wood moves within the wood as liquid or vapor through several types passageways, based on the nature of the driving force (e.g pressure or moisture gradient), and variations in wood structure . These pathways consist of cavities of the vessels, fiber, ray cells, pit champers and their pit membrane opening, intercellular spaces and transitory cell wall passageways.

Movement of water takes place in these passageways in any direction, longitudinally in the cells, as well as laterally from cell to cell until it reaches the lateral drying surfaces of the wood. Capillary forces determine the movement of free water.

It is due to both adhesion and cohesion. Adhesion is the attraction between water and other substances while cohesion is the attraction of the molecules in water to each other. As wood dries evaporation of water from the surface sets up capillary forces that exert a pull on the free water in the zones of wood beneath the surface. When there is no longer any free water in the wood capillary forces are no longer of importance (Langrish and walker 1993).

2.4 Factors affecting wood drying:

The whole art of successful seasoning lies in maintaining a balance between the evaporation of water from the surface of timber and the movement of water from the interior of the wood to the surface. Three factors control water movements in wood the humidity, the rate of circulation and the temperature of the surrounding air.

Temperature has a twofold effect: by influencing the relative humidity of the air it affects the rate of evaporation of water from the surface of the wood, and also within the timber the rate of movement of water from the centre towards the surface.

It is important to appreciate how these three factors interact. The rate of loss of moisture from wood depends on the humidity of the air in immediate contact with surface layers and on the dryness of the layers themselves. The rate of movement of water outwards in a piece of wood is dependent on the vapor pressure of the outer layers being lower than the vapor pressure further in , and on the differences in vapor pressure of successive layers not being excessive.

If the outer layers are appreciably drier than the interior greater resistance is offered to the movement of moisture out ward than when difference in vapor pressure, and consequently in moisture content, of successive layers are smaller; in extreme circumstances resistance may be such that diffusion of moisture

from the inner layers out ward is brought to a standstill, the moisture in the interior of the wood being sealed in .

Resumption of moisture movement in such cases can usually be achieved only by artificial means e.g steaming in a kiln. The relative humidity of the atmosphere, and its temperature, are all important in the seasoning process: the lower the relative humidity of the air the better will it be able to take up moisture from the surface of a Piece of wood (Rosen, Simpson and, Wengert ,1969)

Assuming no temperature changes, as the relative humidity of the air increases, moisture is absorbed by dry wood, and the affinity of the air for further moisture decreases; this, in turn, slows up the drying of the surface of layers of wood exposed to such air. When air absorbing moisture less rapidly, as a result of its relative humidity increasing differences in moisture content of successive inner layers of wood exposed to such conditions will be less marked, the two factors thus combine to reduce seasoning stresses to a minimum. Although this mechanism is of use in drying timbers which are liable to surface splitting in these cases air flow over the surface is purposely restricted . Nevertheless air movement is essential to prevent excessive build-up of relative humidity which may seriously retard or even prevent any drying taking place (Simpson , 1982)

2.5 Energy Requirements for Drying Timber

Water is removed from wood in the form of vapor and a large amount of thermal energy must be supplied to evaporate the water in wood. This energy is the latent heat of vaporization (Q_o) plus an additional amount of energy which must be supplied because of the hygroscopic nature of wood. This additional energy is called the differential heat of sorption (QL). It represents the heat associated with a phase change. It is the energy absorbed in the phase change from free liquid water into bound water in the cell wall. An empirical equation which describes the approximate variation of the differential heat of sorption(Q_L) (BTU,s per pound of water) with moisture content

percent of dry weight at room temperature can be stated as follows:-

$$Q_L = 500 \exp(-0.14M) \quad (1)$$

Where M is the wood moisture content. This means that Q_L increases exponentially with decreasing wood moisture content below the fiber saturation point.

The total heat of vaporization Q_v required to evaporate a pound of water from wood at any given wood moisture content is equal to the sum of the heat of vaporization Q_o of free water and the differential heat of sorption Q_l . At room temperature this is given by:-

$$Q_v = Q_o + Q_l = 1053 + 500 \exp(-0.14 M) \quad (2)$$

For wood above the fiber Saturation point (FSP), the total heat of vaporization Q_v is essentially the same as for liquid water , that is Q_o (1053) Btu). However, it increases toward a value about 1.5 times as great as the wood moisture content approaches zero.

It was found more useful from the view point of lumber drying to know how much energy must be supplied to dry a given volume of lumber through a m.c range. This depends on wood density as well as moisture range covered during drying. Skaar (1977) suggested equation 3 below to calculate energy required per thousand board feet (TBF). The formula states ;-

$$\text{BTU's / TBF} = 51.98(G) (M_w - M_d) (Q_v) \quad (3)$$

Where G = specific gravity of wood

M_w = initial m.c .

M_d = final m.c

Using equation (3) Nasron and Shomo (1983) were able to calculate the mount of intrinsic energy required to dry some Sudanese timber through different m.c range as see in table 2 .

The amount of intrinsic energy required to evaporate the water from 1000 board feet of lumber at 68 F when dried from moisture content M_w (%) to M_d (%).

Table 2.The amount of intrinsic energy required to dry a thousand board feet (TBF) of lumber of some Sudanese wood species.

Species Name	Specific gravity	M _w %	M _d %	Q _v BTU/1b	BTU/TBF X1000
<i>Faiderbida albida</i> (Haraz)	0.401	80	7	1071	1624
<i>Faiderbida albida</i>	0.401	30	7	1109	532
<i>Acacia nilotica</i> (sunut)	0.908	80	7	1071	3288
<i>Acacia nilotica</i>	0.908	30	7	1109	1073
<i>Azadririchat indica</i> (neem)	0.627	80	30	1054	1718
<i>Azadririchat indica</i>	0.627	30	7	1109	831
<i>Balanites aegyptica</i> (higlig)	0.677	80	7	1071	2751
<i>Khaya senegalensis</i> (mahogany)	0.794	30	7	1109	1053

The energy saving realized by air drying or pre-drying prior to final drying are quite evident. It is also evident that it requires more energy to dry woods of higher specific gravity per TPF over a giving moisture content range. So far we have been dealing with intrinsic energy requirement only, that is energy used for removing water from wood. In actual drying practice , however , additional , extrinsic energy must be supplied to compensate for any energy losses or energy wasted because of inefficiency in the application of particular drying operation. It is very difficult to estimate the amount of factors encountered in the drying process . The sum of the energy losses give an

indication to the efficiency of the drying process. Solar dryers control climatic conditions better than does conventional air drying, and conditions are modified so that more heat can be directed to the lumber drying process, thus improving the efficiency of solar drying over that of air drying. Using the intrinsic evaporation energy as 5 percent in air drying , while that of solar drying can be improved up to 15 to 16 percent. With better control in drying kilns efficiencies range between 40 to 50 percent . This indicated that the total energy consumed is tow times or 2.5 times the energy required to supply the intrinsic energy alone in many kiln drying operation. Greenhouse type solar dryers have been even less efficient, absorbing about 6 times as much solar energy as is actually used to evaporate water from timber (Nasroun and Shommo , 1983)

2.6. Benefits of Wood Drying :

The principle objective for seasoning timber is to bring it to the moisture level it will equilibrate at in use. Since it is subject to the differential shrinkage sometimes accompanied by distortion during the process of drying, timber can rarely be used satisfactorily in an entirely green or unseasoned condition .

The efficient seasoning of wood is essential and will help achieve the following results:

- 1- A reduction to the minimum of shrinkage, checking and warping.

- 2- Prevention of blue stain and incipient decay.
- 3- Reduction of liability to some form of insect attack.
- 4- Increase in strength.
- 5- Reduction in weight and freight cost.
- 6- Improvement of conditions suitable for painting, gluing, and preservative treatment.

Converted timber is treated very roughly and used inefficiently in this country (Nasroun 1979). Drying timber is one of the method of adding value to sawn products from the primary wood processing industries. However, currently used conventional drying processes often result in significant quality problems from cracks, both internally and externally reducing the value of the product .Thus proper drying under controlled conditions prior to use is of great importance in timber use, in countries where climatic conditions vary considerably at different times of the year. Drying if carried out promptly after felling of trees and sawing protect timber from primary decay (Anon ,1997) .

2.7 Drying Defects:

Some field observation on telegraph poles in service at different localities showed various causes of damage. This in addition to other observations made at various timber depots and sawmills, which clearly illustrate that splitting is the major cause of timber losses and failure. The inherent value of a timber and its

potential commercial uses are generally affected by the nature and the magnitude of the defects that occur during drying. In the north and central parts of Sudan the combination of high temperature and low relative humidities result in an equilibrium moisture content of between 4 and 8 percent, depending on the species and season for more than nine months. Under such conditions excessive splitting and end checking are liable to occur (Nasroun, 1979). When green wood dries, The first water to leave it is the free moisture in the cavities (lumina) of the cells. No normal dimensional changes accompany this stage in the drying process. When, however, the drying is continued below the fiber saturation point shrinkage take place. The shrinkage is not equal in all direction ,because of the anisotropic nature of the wood. Most seasoning defects can be minimized by careful air seasoning and by proper control of drying conditions in the kiln. There are two types of drying defects one of them is from shrinkage anisotropy resulting in warping (cupping ,bowing , twisting , crooking , spring and diamonding) and the second is from uneven drying resulting in the rupture of the wood tissue such as end and surface checks, internal splits, honeycombing, case-hardening and collapse (Pashin and deZeeuw , 1980) .

Shrinkage and swelling

Shrinkage and swelling may occur in wood when the moisture content changes below FSP. Shrinkage occurs as moisture

content decreases below FSB, while swelling takes place when m.c. increases. Volume change is not equal in all directions. The greatest dimensional change occurs in a direction tangential to the growth rings. Shrinkage from the pith outwards, or radially, is usually considerably less than tangential shrinkage, while longitudinal (along the grain) shrinkage is so slight as to be usually neglected. The longitudinal shrinkage is 0.1% to 0.3%, in contrast to transverse shrinkages which is 2% to 10%. Tangential shrinkage is often about twice as great as in the radial direction, although in some species it is as much as five times as great. The shrinkage is about 5% to 10% in the tangential direction and about 2% to 6% in the radial direction (Stamm, 1964).

Differential transverse shrinkage of wood is related to:

1. the alternation of latewood and earlywood increments within the annual ring
2. the influence of wood rays on radial direction
3. the features of the cell wall structure such as microfibril angle modifications and pits; and the chemical composition of the middle lamella (Kollmann and Cote, 1968).

Warp:

Warp in lumber is any deviation of the face or edge of a board from flatness or any edge that is not at right angles to the adjacent face or edge (squares). It can cause significant volume and grade loss. All warp can be traced to two causes; differences between radial, tangential, and longitudinal shrinkage in the piece as it dries, or growth stresses. Warp is also aggravated by irregular or distorted grain and the presence of abnormal types of wood such as juvenile and reaction wood. Most warp that is caused by shrinkage difference can be minimized by proper stacking procedures. The effects of growth stresses are more difficult to control but certain sawing techniques are effective and will be described later. The five major types of warps are cup, bow, crook, twist, and diamonding. Cup is the distortion of a board in which there is a deviation flat wise from a straight line across the width of a board. It begins to appear fairly early in

drying and becomes progressively worse as drying continues. Cup is caused by greater shrinkage parallel to an radial shrinkage. The greater the degree of cup than across the growth rings. In general, the greater the difference between tangential Thinner boards cup less than thicker ones. Because tangential shrinkage is greater than radial shrinkage, flat sawn boards cup toward the face that was closest to the bark. A flat sawn board cut near the bark tends to cup less than a similar board cut near the pith because the growth ring curvature is less near the bark. Similarly, flat sawn boards from small-diameter trees are more likely to cup than those from large-diameter trees. Due quarter swan boards do not cup. Cup can cause excessive losses of lumber in machining. The pressure of planer rollers often splits cupped boards. Cup can be reduced by avoiding over drying. Good stacking is the best way to minimize cup. (Desh and Dinwoodie, 1996) Bow is a deviation flat wise from a straight line drawn from end to end of aboard. It is associated with longitudinal shrinkage in juvenile wood near the pith of tree, compression or tension wood that occurs in leaning trees, and cross grain. The cause is the difference in longitudinal shrinkage on opposite faces of a board. Assuming that there are no major forms of grain distortion on board faces, bow will not occur if the longitudinal shrinkage is the same on opposite faces. Crook is similar to bow except that the deviation is edgewise rather than flat wise. While good stacking practices also help reduce crook, they are not as effective against this type of warp as they are against cup and bow. Twist is the turning of the four corners any faces of aboard so that they are no longer in the same plane. It occurs in wood containing spiral, wavy, diagonal, distorted, or interlocked grain. Lumber containing these grain characteristics can sometimes be dried reasonably flat by wing proper stacking procedures. Twist, bow, and crook have definite allowable limits in the grading rules for softwood dimension lumber, so it is desirable to minimize these defects. Diamonding is a form of warp found in squares or thick lumber. In square, the cross section assumes a diamond shape during drying. Diamonding is caused by the difference between radial and tangential shrinkage

in squares in which the growth rings run diagonally from corner to corner. It can be controlled somewhat by sawing patterns and by air drying or pre-drying before kiln drying (Walker et al, 1993)

Rupture of wood tissue:

The chief difficulty experienced in the drying of timber is the tendency of its outer layers to dry out more rapidly than the interior ones. If these layers are allowed to dry much below the fiber saturation point while the interior is still saturated, stresses (called drying stresses) are set up because the shrinkage of the outer layers is restricted by the wet interior. Rupture in the wood tissues occurs, and consequently splits and cracks occur if these stresses across the grain exceed the strength across the grain (fiber to fiber bonding). The successful control of drying defects in a drying process consists of maintaining a balance between the rate of evaporation of moisture from the surface and the rate of outward movement of moisture from the interior of the wood. The way in which drying can be controlled will now be explained. One of the most successful ways of wood drying or seasoning would be kiln drying, where the wood is placed into a kiln compartment in stacks and dried by steaming, and releasing the steam slowly. Many defects that occur during drying are a result of the shrinkage of wood as it dries. In particular, the defects result from uneven shrinkage in the different directions of a board (radial, tangential, or longitudinal) or between different parts of a board, such as the shell and the core. Rupture of wood tissue is one category of drying defects associated with shrinkage. Knowing where, when, and why ruptures occur will enable an operator to take action to keep these defects at a minimum. Kiln drying is frequently blamed for defects that have occurred during air drying, but most defects can occur during either process. In kiln drying, defects can be kept to a minimum by modifying drying conditions, an in air drying, by altering piling procedures. (key et al, 2000).

Surface checks:

Surface checks are failures that usually occur in the wood rays on that flat sawn faces of boards. They occur because drying stresses exceed the tensile strength of the wood perpendicular to the grain, and they are caused by tension stresses that develop in the outer part, or shell, of boards as they dry. Surface checks can also occur in resin ducts and mineral streaks. They rarely appear on the edges of flat sawn boards 6/4 or less in thickness but do appear on the edges of thicker flat sawn or quarter sawn boards. Surface checks usually occur early in the drying, but in some softwood the danger persists beyond the initial stages of drying. They develop because the lumber surfaces get too dry during air drying. Thick, wide, flat sawn lumber is more susceptible to surface checking than thin, narrow lumber. Many surface checks particularly those in hard woods, close in the later stages of drying. This occurs when the stresses reverse and the shell changes from tension to compression. Closed surface checks are undesirable in products and furniture. (Allen, and Pierson, 1980)

End checks and splits:

End check, like surface checks usually occur in the wood rays, but on end-grain surfaces. They also occur in the early stages of drying and can be minimized by using high relative humidity or by end coating. End checks occur because moisture moves much faster in the longitudinal direction, than in either transverse direction. Therefore the ends of boards dry faster than the middle and stresses develop at the ends. End checked lumber should not be wetted or exposed to high relative humidity before any further drying, or the checks may be driven further into the board. The tendency to end check becomes greater in all species as thickness and width increase therefore the end-grain surfaces of thick and wide lumber squares, and gunstocks should be end coated with one of the end coatings available from kiln manufacturers and other sources. To be most effective, end coatings should be applied to freshly cut, unchecked ends of green wood. End splits often result from the

extension of end checks further into a board. One way to reduce the extension of end check into longer splits is to place stickers at the extreme ends of the boards. End splits are also often caused by growth stresses and therefore not a drying defect. End splits can be present in the log or sometimes develop in boards immediately after sawing from the log (Becker, 1982).

Collapse:

Collapse is a distortion, flattening, or crushing of wood cells. In these severe cases, collapse usually shows up as grooves or corrugations, a wash boarding effect, at thin places in the board. Slight amounts of collapse are usually difficult or impossible to detect as the board level and are not distinct grooves or corrugations and this creates a problem. Sometimes collapse shows up as excessive shrinkage rather than collapse.

Collapse may be caused by:

- (1) compressive drying stresses in the interior parts of boards that exceed the compressive strength of the wood
- (2) liquid tension in cell cavities that are completely filled with water.

Both of these conditions occur early in drying, but collapse is not usually visible on the wood surface until later in the process. Collapse is generally associated with excessively high dry-bulb temperatures early in kiln drying and thus low initial dry-bulb temperatures should be used in species susceptible to collapse:

Although rare, collapse has been known to occur during air drying. Collapse is a serious defect and should be avoided if possible. The use of special drying schedules planned to minimize this defect is recommended. Some species susceptible to collapse are generally air dried before being kiln dried. In many cases, much excessive shrinkage or wash boarding caused by collapse can be removed from the lumber by reconditioning or steaming. This treatment basically consists of steaming the lumber as near as possible to 212 F and 100 percent relative humidity. Reconditioning is most effective when the average moisture content is about 15 percent, 4 to 8 h are usually required. Steaming is corrosive to kilns, and unless collapse is a

serious problem that can not be solved by lowering initial drying temperatures, steaming may not be practical. (Simpson, 1975)

Honeycomb:

Honeycomb is an internal crack caused by a tensile failure across the grain of the wood and usually occurs in the wood rays. This defect develops because of the internal tension stresses that develop in the core of boards during drying it occurs when the core is still at a relatively high moisture content and when drying temperatures are too high for too long during this critical period. Therefore, honeycomb can be minimized by avoiding high temperatures until all the free water has been evaporated from the entire board. This means that the core moisture content of boards should be below the fiber saturation point before raising temperature because that is where honeycomb develops. When the average moisture content of entire sample boards is monitored for schedule control, there is no direct estimate of core moisture content.

Depending on the steepness of the moisture gradient, which is often unknown in most kiln-control schemes, the core moisture content can be quite high even when the average moisture content of the whole sample is low. The danger is that schedule changes based on average moisture content that call for an increase in dry bulb temperature can be made too soon while moisture content in the core is still high, thus predisposing the wood to honeycomb. Measurements of shell and core moisture content should be taken before these dangerous schedule changes are made. Deep surface and end checks that have closed tightly on the surface of lumber but remain open below the surface often called honeycomb, but they are also known as bottleneck checks. Honeycomb can result in heavy volume losses of lumber. Unfortunately, in many cases the defect is not apparent on the surface, and it is not found until the lumber is machined. Severely honeycombed lumber frequently has a corrugated appearance on the surface, and the defect is often associated with severe collapse. (Christensen and Barker, 1973)

CHAPTER THREE

MATERIALS and METHODS

3.1 Construction of Dryers

For constructing and designing the dryers use was made of the wooden frames erected in a previous investigation by Nasroun *et al* (2013). These included an air dryer and two greenhouse type solar dryers. The designs of the two solar dryers were altered from those of the previous investigation mentioned above according to some recommendations mentioned in that study to ensure better flow of the heated air into the timber stacks. The alterations included the orientation of the timber stacks, the positions of collectors, fans and vents. The three different dryers were constructed at Suki sawmill, Sennar State. They were of wooden frame Construction. The two green house type solar dryers differed from one another in the position, area and orientation of the collectors as well as the way of transferring heated air inside the dryer. All walls and roofs of the two solar dryers were made of one layer of transparent plastic sheet. The collectors in the solar dryers consisted of black-painted corrugate zinc absorber plates. The air dryer was a shed with corrugated zinc roof to shade the wood stack but with no side walls, in order to facilitate the flow of natural air into the stack .

The first solar dryer denoted(S H) had a total area of 4 by 4 meters . The collector was placed above the timber stack and below the roof. The area of the collector was approximately 12 square meters. The second solar dryer had a low flat collector on the dryers floor on the northern side of the timber stack denoted (SL). The area of the collector was only 12 squer meters the total area of this dryer was 4 by 6 square meters, running north/south.

3.2 Methodology:-

The research program consisted of two trials (Charges), one in summer and the other in winter. The summer charge was

carried out in the summer of 2013 between April 5th and May 30th., while the winter charge was carried out between January 5th and 20th of February 2014. The set- up in the two solar dryers differed between the summer and winter charges. All stacks in all dryers and seasons had east/west orientation.

In summer the collector of SH was tilted slightly to the north. One 18-inch electrical fan was set immediately under the roof on the northern wall to push the heated air above and below the collector and over the stack to the other side, where there was another fan at a lower level of the southern wall, facing the timber stack, to push the heated air into the timber stack . The timber stack was oriented east/west . Two small vents, 30 by 30 cm were cut on the northern wall at about 50 cm above ground level for getting rid of humid air during drying.

The same procedure as in the summer charge was followed in winter but with some changes in the set-up. The collector was tilted to face the south at an angle which will make it approximately perpendicular to the mean position of the sun at noon at that particular latitude. Only one fan was used. It was placed on the northern wall facing the timber stack. The vents were moved to the southern wall.

In the summer charge SL had the collector flat on the floor on the northern side of the timber stack. The electrical fan was set on the northern wall to push the heated air over the collector into the timber stack. Two small vents, 30 by 30 cm each were set on the opposite (southern) wall to facilitate the removal of excess humidity during drying. The vents were placed about 50 cm above ground level and were one meter apart. The same set-up was used in the winter charge except that the collector was tilted to face the south.

In both charges the stacks in the three dryers consisted of 80 (2" x 4" x10')(5cm x10cm x 3m) sunt (*Acacia nilotica*) boards each. They were stacked in 10 rows with 8 boards in each row.

The stickers between the rows were 1.5 inch thick. Three sample boards were selected in each stack for periodic weighing and m.c determination .The three sample boards for each stack were place at different levels in the stack, one at the bottom of the stack (the middle of the second row from the bottom), one at the top of the stack (The middle of second row from the top) and one in the middle of the stack. The initial weight and initial m.c of each board were recorded together with its expected dry weight. Each board was taken out of the stack every three days, weighed and returned to the stack. The dry bulb and wet bulb thermometer readings were recorded and the relative humidity worked out. The moisture content was calculated from the periodic weights obtained.

With regards to statistical analysis, analysis of variance was carried out, followed by Duncan's multiple range test, looking for differences in drying rates between the three dryers. This was followed by regression analysis to look for trends relating m.c to time for the samples with the lowest initial m.c in the three dryers .

Cost of constructing the dryers

A rough estimate for the costs of constructing the three types of dryers was made to to compare them with the average cost of traditional electric or steam operating wood drying kiln.

CHAPTER FOUR

RESULTS AND DISCUSSION

Summer Charge :

Table 1. shows the variation of environmental conditions during the summer charge in the three dryers with time . It indicates that the maximum temperatures reached in the two solar dryers , SL and SH were 52° C and 47° C respectively . These were significantly higher than the ambient temperature (from air dryer) which was 44° C . R . H % , on the other hand , varied between 10% and 26 % in the air dryer , 18% and 25 % in SH and 4% and 19% for SL .

Table 1. variation of temperature and R.H with time in the three dryers in summer.

Dryer type	variable	Variation temperature and R.H with time											
		3	6	9	12	15	18	21	24	27	30	33	36
AD	DBT	35	34	45	41	44	41	43	43	41	42	40	40
	wBT	17	16	17	18	20	18	25	20	20	20	20	24
	R.H	13	13	13	10	10	10	23	12	13	12	14	26
SL	DBT	50	43	49	50	52	48	50	48	48	49	45	42
	wbT	26	24	26	26	55	25	26	25	25	55	23	25
	R.H	5.0	19	5	5	4	5	5	5	5	5	5	5
SH	DBT	44	43	45	43.5	45	44	45	45	47	47	42	42
	wBT	26	24	25	24	26	25	25	25	26	27	25	25
	R.H	24	19	20	19	21	20	19	19	18	21	25	25

AD = air dryer

SL = solar dryer with lower collector

SH= solar dryer with high collector

DBT = dry bulb temperature

WBT = wet bulb temperature

Table 2, on the other hand , shows the variation of m.c with time in the summer charge in the three dryers .In air drying sample (B) progressed regularly to 12.3% as the lowest m.c.in this dryer. Sample A and sample C in the same dryer were not far off from sample B . They ended up with slightly higher m.c. than sample B, 13.9% and 12.8% respectively . These results

and the environmental conditions shown in table 1 and summarized in table 3 which shows the means as obtained from the statistical analysis for the three types of dryers .

Table 2. Variation of moisture content percent with time in summer charge :

Dryer type	Sample	Variation of moisture content with time in days										
		3	6	9	12	15	18	21	24	27	30	33
AD	A	43.7	35.7	31.7	27.8	23.8	21.1	18.5	17.2	16.5	14.5	13.9
	B	36.9	30.1	27.8	24.6	21.9	19.1	16.4	16.4	16.4	13.0	12.3
	C	36.5	29.8	27.4	23.7	21.3	18.9	16.4	15.8	15.2	13.4	12.8
SL	A	36.7	30.1	27.1	23.4	19.8	16.8	16.8	15.0	13.8	13.2	12.0
	B	37.3	30.8	27.6	24.3	21.9	19.5	17.8	16.2	16.2	14.6	13.8
	C	32.1	25.5	21.8	17.5	14.5	12.4	10.9	9.4	10.2	8.7	8.0
SH	A	42.3	31.2	26.3	21.5	18.0	14.5	11.8	11.1	10.4	9.0	8.3
	B	39.1	31.4	27.5	23.7	21.1	17.9	15.3	14.1	13.4	12.1	11.5
	C	36.1	30.6	24.5	20.2	17.7	15.3	12.2	11.0	11.0	9.2	8.5

- AD = Air dryer
- SH = Solar dryer with high collector
- SL = Solar dryer with low collector

In the case of solar dryer with high collector(SH) the average initial m.c (39.1%) was approximately equal to that of the air dryer (39. %) (Table 3), but the average final m.c in SH (9.5%) was significantly lower than that of air drying (12.3%) .This is due to the higher temperature in SH and may also be due to the air flow caused by the fans and the location of the vents . However, solar dryer (SL) started with a lower initial m.c (35.4%) and reached a lower final initial m.c (11.2%) than air drying . According to the environmental conditions in the two solar dryers , (SH) ,with lower average temperature and higher average initial m.c. should have had a higher average final m.c than SL, but the former ended up with a lower average final m.c. than the latter . This may mean that the circulation of the heated air in SL was not directed properly , which in turn may indicate that the orientation and location of the fans and vents should be adjusted in the coming trials. The best option for an SL dryer will be a design with an external collector.

Table 3 . average R.H levels, average temperature , average M.C and average final M.C in the different dryers in summer.

Type of dryers	Average R.H %	Average Temperature c ⁵	Average initial MC%	Average final MC%
Air dryers	14.0 b	40.1 c	39.0	12.3 a
Solar dryers with high collector(SH)	25.0 a	44.4 b	39.1	9.5 b
Solar dryers with low collector (SL)	6.0 c	47.8 a	35.4	11.2 a

Figure 1 also shows the same trend and indicated that SH had the highest rate of drying followed by SL and lastly the air dryer. It shows the progress of drying in the samples with the lowest initial m.c , in the three dryers .

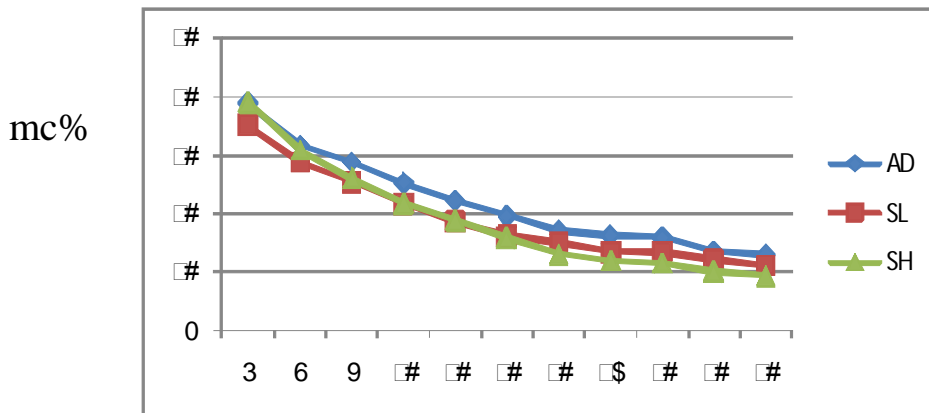


Figure 1. The progress of drying in samples with the lowest initial m.c. in the three dryers in summer

Winter charge :

Table 4 shows the variation of environmental conditions with time in the three dryers in winter . In the air dryer the temperature varied between 30 and 40° C, while R.H% changed between 11% and 33% . In solar dryer with high collector (SH) the temperature varied between 35 and 50° C , while RH% changed between 10% and 40% . In solar dryer with low collector (SL), however , the temperature varied between 45 and 50° C , while R.H% changed between 20% and 50% .

Table 4. changes in environmental conditions with time in the three dryers for winter charge .

Dryer taype	sample	Variation of moisture content with time in days									
		3	6	9	12	15	18	21	24	27	30
AD	D.B.T	30	35	32	34	38	39	38	39	42	45
	w.B.T	18	18	19	21	18	21	21	22	28	25
	R.H	30	28	30	11	18	20	22	33	20	28
SH	D.B.T	35	40	43	46	45	40	50	42	44	49
	w.B.T	18	28	27	29	27	30	27	29	26	28
	R.H	40	29	29	25	32	10	37	25	30	23
SL	D.B.T	45	50	46	48	45	48	50	45	46	50
	w.B.T	35	38	26	29	25	27	32	27	27	33
	R.H	50	20	24	20	22	30	25	27	44	25

A.D=air dryer

S.H = Solar dryer with high collector (above the wood stack) .

SL = Solar dryer with low collector (at ground level)

D.B.T= dry bulb temperature.

w.B.T = wet bulb temperature.

Table 5 shows the progress of the drying process for the winter charge in the three dryers during the 30 days of the experiment . Due to some delays in stacking the timber , some samples lost appreciable amount of moisture after their initial m.c % was determined. Some of them reached close to fiber saturation point (FSP) like sample C in air drying sample A , B and C in (SH) and sample C in (S L)

Table 5 variation in moisture content with time in the three dryers in winter .

Dryer type	sample	Variation of moisture content with time in days										Ave–Final M.C%
		3	6	9	12	15	18	21	24	27	30	
AD	A	39.4	29.2	26	15.8	15	14.2	14.2	13.4	12.6	12.6	
	B	44.6	37	34.2	20.9	20	19	19	18.1	17.2	16.2	16.2
	C	35.4	30.5	23.6	15.7	12.8	11.8	10.8	10.8	9.9	8.9	
SH	A	36.2	27.2	22.4	17.4	16.4	12.2	11.5	9.5	8.5	8.5	
	B	33.4	24.7	23.7	10.2	10.2	10.2	9.2	7.3	7.3	4.4	5.6
	C	31.3	24.2	22.4	11.8	10.9	10	8.2	7.3	5.5	3.8	
SL	A	50.8	30.8	30.8	26.8	17.1	15.5	14.7	13.9	13.9	12.3	
	B	41.8	36.7	29.8	20.3	17.7	16	16	14.3	12.6	12.6	10.4
	C	36.2	29.1	25.6	19.5	14.2	11.5	11.5	9.8	9.4	6.3	

AD= air dryer

SH = solar dryer with high collector .

SL = solar dryer with low collector

The progress of drying of samples with initial m.c higher than fiber saturation point in each dryer was followed . The samples comprised the following : Sample B in air drying showed the slowest rate of drying and ended up to 16.2% final m.c after 30 days . Sample A in SH reached a final m.c of 8.5%, while sample A of solar dryer SL had an intermediate rate of drying and intermediate final m.c (12.3%) compared to the other two dryers. By looking at the samples with the lowest initial m.c in each dryer (sample C in all three dryers) we got a rough estimate of the equilibrium m.c (EMC) under all three conditions which is the m.c content which remains constant at the end if the drying .

The equilibrium m.c of Suki area (from sample C in air drying) was about 8.9% . In solar dryer (SH) EMC was 3.7% , whereas in solar dryer SL it was 6.3% (Table 5 and 6). Table 6 shows the results of the statistical analysis as a summary of table 4 and table 5 . These tables also indicate that the average final m.c

which was significantly different between the dryers ($P=0.05$). The lowest was in case of SH (5.6%) , followed by SL (10.4%) , without a significant difference between them and highest in case of air drying (12.6%) with a significant difference from SH but without significant difference from SL. This means that the equilibrium m.c for Suki area in winter is about 8.9% and that the two solar dryer can dry timber to m.c lower than the equilibrium m.c of the area These results were close to what was found by Nasroun *et al* .(2013) . They found that the EMC of Suki area in winter was 9.2% , in SH it was 6.7% and in SL it was 7.5% .

All these results indicate that the solar dryer with high collector (SH) is the most efficient of the three dryers , followed by solar dryer (SL) and lastly air drying . Air drying also resulted in the highest equilibrium m.c and highest final m.c because it was exposed to significantly lower temperature than the two solar dryer ($P=0.0001$) (Table 6) . The two solar dryers had significantly higher temperature than the ambient temperature (from air drying) . Air dryer also had a lower R.H. than the other two dryers .

Table 6 Summary of average temperature , R. H, final moisture content and equilibrium m.c. for the three dryers :

Type of dryer	Temperature ° C	R.H %	Average final M.C%	EM C %
Air dryer	37.2 b	23.8 a	12.6 a	8.9
Solar dryer with high collector (SH)	44.0 a	28.0 a	5.6 b	3.8
Solar dryer with low collector (SL)	47.3 a	27.6 a	10.4 ab	6.3

The results obtained from SH were close to the results obtained by Beckkioui *et al* . (2011). They were working in India and they found that a period of 17 days was needed to dry pine wood in a solar dryer from 35% to 10% m.c. Sample B and C in SH showed similar rates of drying (Table 5). This, in spite of the big difference in densities and permeability between sunt wood and

pine wood. Helwa *et al.* (2004) also obtained similar results. The adjusted set up for SH in the winter charge in this investigation proved to be a reasonably efficient set up for commercial application after taking some minor precautions.

Drying Defects:

Sunt wood showed high resistance to any drying defects during the drying process. No clear surface checks or splits were observed. However, some shakes which were present before starting the drying process were there. These shakes occur on the growing tree as a result of growth stresses or effect of wind on trees. Only minor warping incidences in the form of bowing were observed on a few air dried boards only and hardly any bowing on the solar dried boards. This may be due to the accumulation of humidity in the two solar dryers from time to time when the vents are closed, while the air flow in the air dryer is continuous with no accumulation of humidity within the stack. All these results indicate that sunt wood can be dried at reasonable rapid rate with minimal drying defects. In kiln drying it will cope with fairly severe rapid drying schedules. To have a better comparison for the effect of the dryers on drying defects it will be better to use a fragile wood instead of the stable sunt wood. It will be better to use eucalypts in future trials.

Costs of constructing the dryers

The estimated costs of constructing the three types of dryers are given in table 7. The cost of constructing SL dryer was highest because its area was the biggest to accommodate both the collector and the timber stack. This big area made SL dryer much less efficient than SH dryer. Even the costs favor SH dryer as it has a lower cost than SL dryer and much more efficient. The cost of constructing SH dryer (SDG.3566) is nothing compared to the cost of buying and installing traditional electric or steam operated wood drying kilns . These costs range widely reaching up to US \$.50000 but averaging between US \$.10 – 15.

Therefore, SH is a cost effective energy saver design which can be used commercially by taking some minor precautions.

Table 7. Estimated cost of constructing the dryers (SDG)

Item	Air dryer	SH	<u>SL</u>
Cost of material	1992	2866	4688
Cost of construction	600	700	900
Total cost	2592	3566	5588

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations could be drawn from this study:

Conclusions:-

- It was obvious from this investigation that SH was the most efficient dryer, with the fastest rate of drying among the three dryers.
- The design and set up of SH for the winter charge proved to be the best set up.
- With better control of air circulation within the dryers, both types of solar dryers can dry wood to m.c lower than the EMC of any area.
- Sunt wood proved to be a stable, durable wood which can be dried at a reasonably rapid rate without much degradation.

Recommendations:

- The design and set up of SH used in the winter charge is recommended for commercial application.
- With SL an external collector should be tried in order to increase the heating surface and reduce the area of the dryer.
- In the future trials it will be better to use more fragile wood species, like the eucalypts, to have a better idea about the effect of solar dryers on drying defects.

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