CHAPTER 1

INTRODUCTION

In many countries, wood industry is one of the most important business affecting the income of those countries. That is not only due to the direct benefits from the forest they can get (e.g. construction materials, furniture) but also the benefits from other products such as some kinds of leaf which can be used as drugs or drugs'compositions.

Throughout this thesis the words "wood", "timber" and "veneer" appear many times, however these terms are not synonymous. Wood describes the material of which trees are made, timber can refer to standing trees, but it also means wood cut from trees for constructional purpose, veneer means the sheet of wood peeled from trees.

The principal ways in which wood is utilized are shown in Figure 1.1 and it is perhaps surprising to see that half is burnt. However, it should be remembered that throughout the world, wood was the main source of energy and fuel until the 1850's. The use of wood as a fuel now occurs mainly in developing countries such as tropical Africa (Fig. 1.2) and South America. As nations advance technologically they depend less on wood for fuel: in Brazil between 1967 and 1973, for example, the contribution of wood to the total production of energy dropped from a half to a quarter. Those of us who live in industrialized countries should recognize that our energy sources; coal, gas and oil come from the decayed forests of long age. Once consumed, these fuels would take millions of years to renew. Some scientists believe that, with careful management, present-day forests could provide a never-ending supply of firewood and charcoal (Fig. 1.3) and hence a very cheap source of energy.

Another important use for wood is in paper-making. Stone, wood and silk are among the many materials on which civilizations recorded everyday events, but "paper-making", using rags, was not invented until AD 105 (in China). Even today, materials such as bamboo, esparto grass, bagasse (sugar cane waste) and rags are sometimes employed instead of wood pulp. It was only in the late fifteenth century that paper-making was introduced into Europe and up to the nineteenth century, every piece of paper was hand-made.

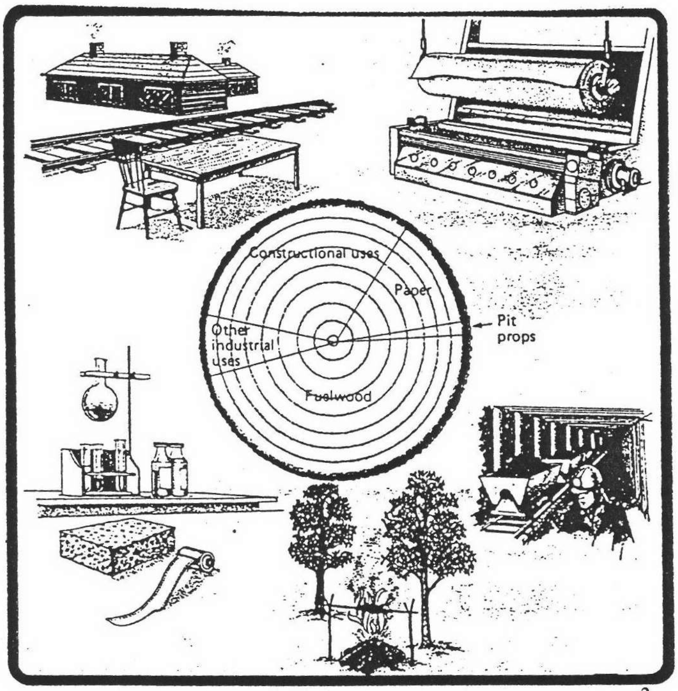

Fig. 1.1 *In 1975 the world's forest crop was over 2500 million* m^3. *The diagram shows the main uses for this enormous quantity of wood.*

Fig. 1.2 *Each year about half the wood felled on the forest is burnt. A canoe is being used in Nigeria to transport a load of fuelwood to the village.*

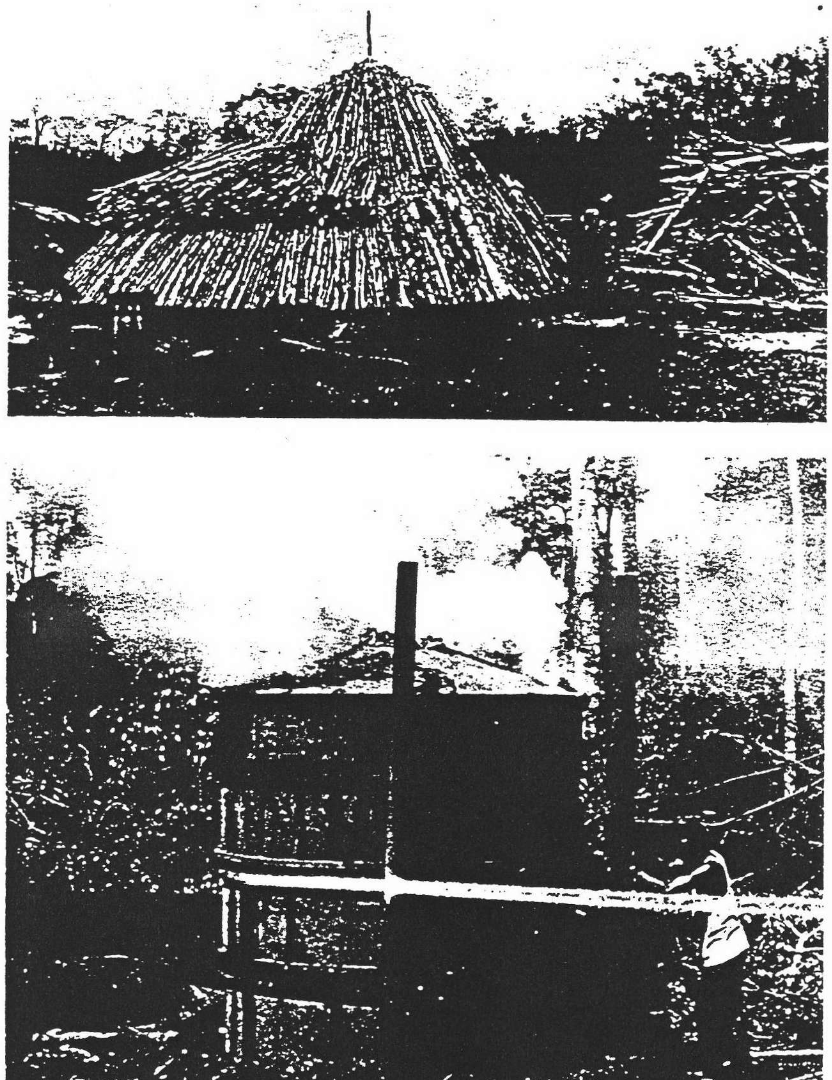

Fig. 1.3 Charcoal burning is a centuries-old industry still important in many developing countries. The simplest method is to burn a large stack of wood (top) as in Cuba, more elaborate is the kiln (bottom) used in Uganda, which converts 100 m3. of otherwise wasted wood to 6,000 kg. of charcoal in a month.

As with many industries, mechanization and automation (Fig. 1.4) markedly increased production. The amount of wood converted each year continues to rise and it was

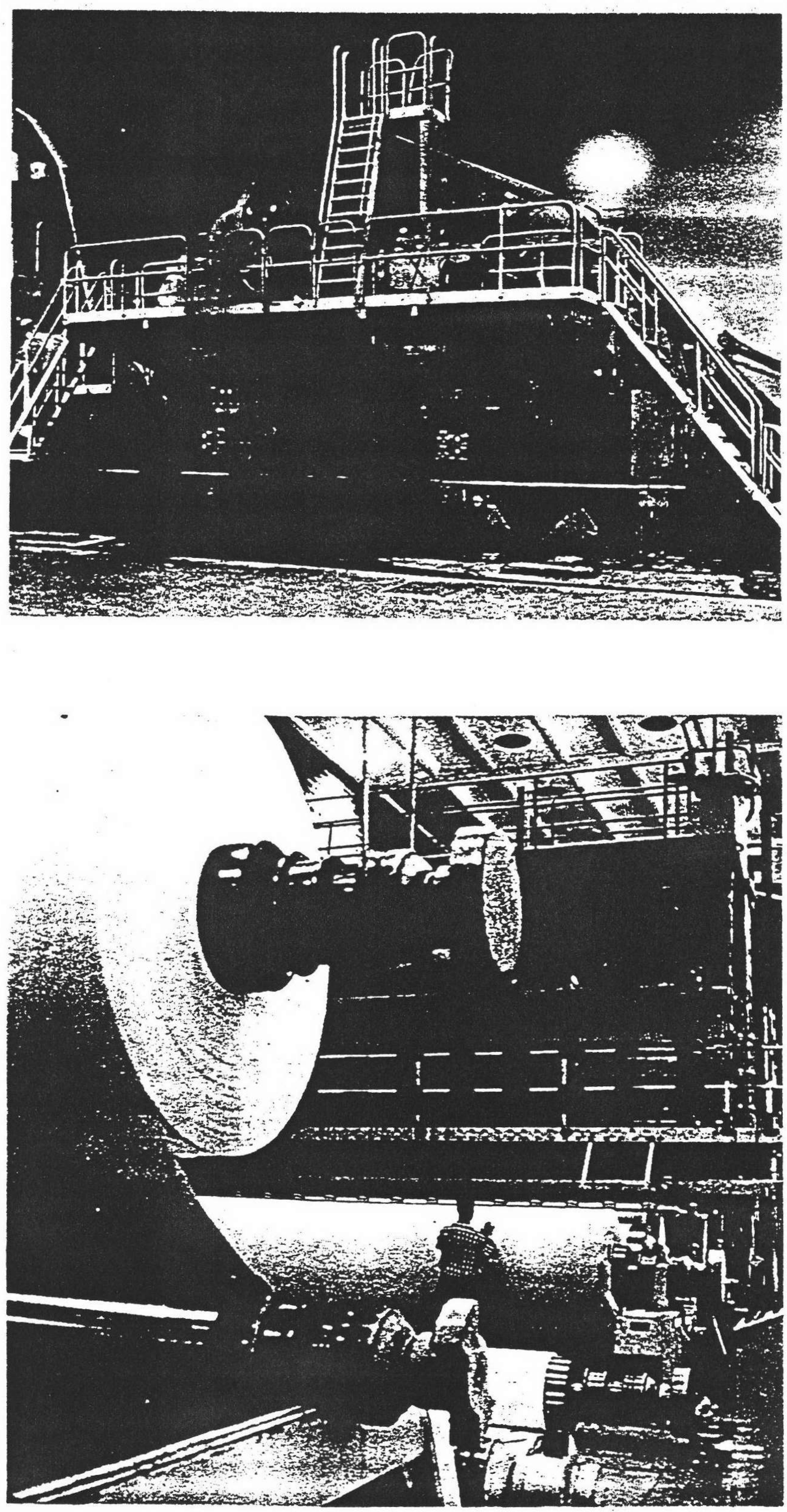

Fig. 1.4 Paper production consumes large amounts of wood every year: (top) paper-making in progress; (bottom) inspecting the huge rolls of paper at a Finnish mill.

recently estimated that meeting the world's annual demand for pulp and paper requires the harvesting of forest the size of the U.K..

Finally, over 5,000 different types of wood products are currently manufactured. Certain of these have been known for a long time, for example cellulose, lacquers, wood alcohol and artificial silk. Others are more recent, one rapidly-growing application for wood is in a manufacture of board products, such as plywood, particle board, fibre board and also in furniture making. These products are mostly produced from veneer sheets in different sizes. In plywood manufacturing, wood is peeled to be sized of about 4 ft. x 8 ft. but in furniture making, veneer is used for some parts of chairs or tables. Veneer will be cut in small pieces which sized of about 300 mm. x 500 mm.. As same as in plywood manufacturing, many sheets of veneer are sticked together with glue and brought to be cut, bent to appropriated size and shape as shown in Fig. 1.5.

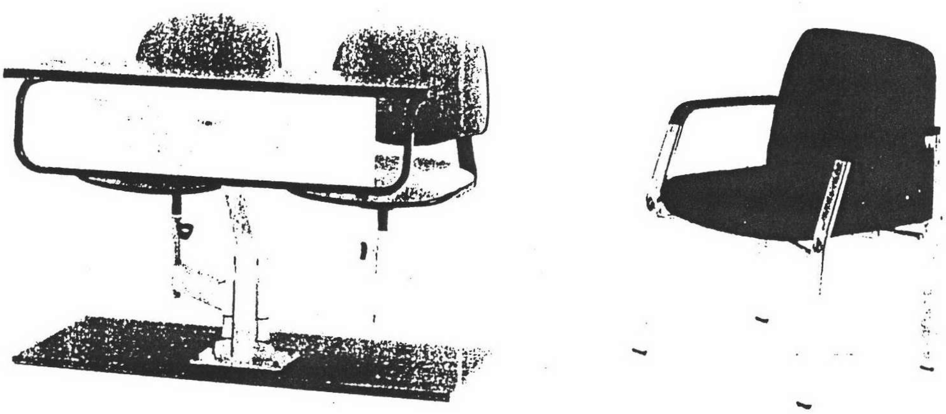

Fig. 1.5 *In furniture making, veneer sheets are some part of furniture such parts are made from veneer sheets bent to be required pattern.*

But the most usefulness of the forest for human is that it balances the climate and originates the water sources for people.

Since the forests all over the world are depleted and no other resources can be replaced, governments of most countries are considering in the decreasing of raw material which means wood in this case. So the strong policies for controlling the forestry area have to be set up.

Eventhough some synthetic materials, e.g. plastic, fibre, are much more used as compensated materials, wood industry has still continues its manufacturing because of its specific properties making it to be the only material used in some industries.

The advantage specific properties of wood are as follows

1) Wood can be easily worked with tools and machines and, weight by weight, can support greater load than steel.

2) It can be connected to the others with nail, or glue by using simple equipments.

3) Dried wood will be little expanded or retracted comparing to other materials.

4) Wood is very durable when it is used in suitable condition.

5) There is no chemical corrosion for wood since its compositions have no severe reaction with any chemical substance.

6) Wood is a resistant to mild chemicals and insulates against electricity and heat (Fig. 1.6) because of its cellular structure and air trapped inside.

7) Wood can absorb the vibrated force better than any material.

8) Wood is the most suitable material for furniture production because it is available in a wide variety of grain patterns, colours and density.

Despite its many good features, wood has also disadvantage properties as follows, (See also Fig. 1.7):

1) Wood can be easily burnt, it is one of the most widely used fuel.

2) It can be attacked by insects, fungi and marine borers.

3) It shrinks and swell with changes in humidity.

4) The strength of wood is not the same in all directions.

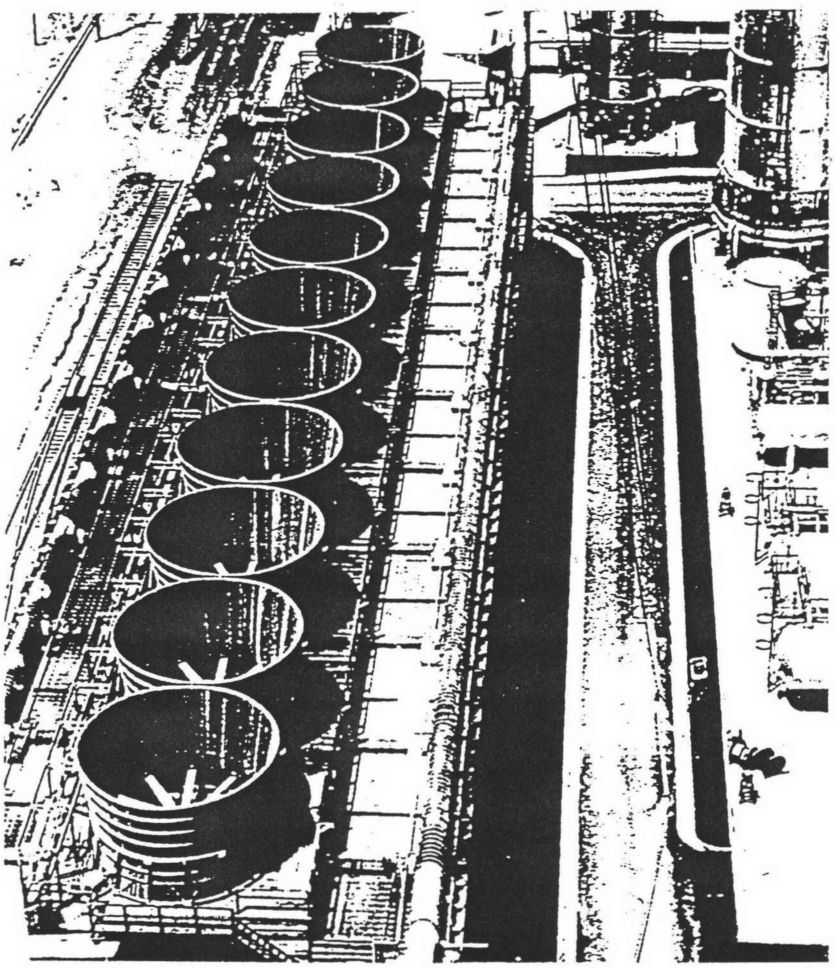

Fig. 1.6 *These cooling towers, built of California redwood (Sequoia sempoervirens), are used to cool hot water at the Avon Refinery, California. This very durable timber is strong for its weight, a good insulator and resistant to chemicals. Redwood tanks and vats are much used in the textile, paint, leather, soap, pulp and paper, and mining industries for containing harsh solutions of acids and alkalis.*

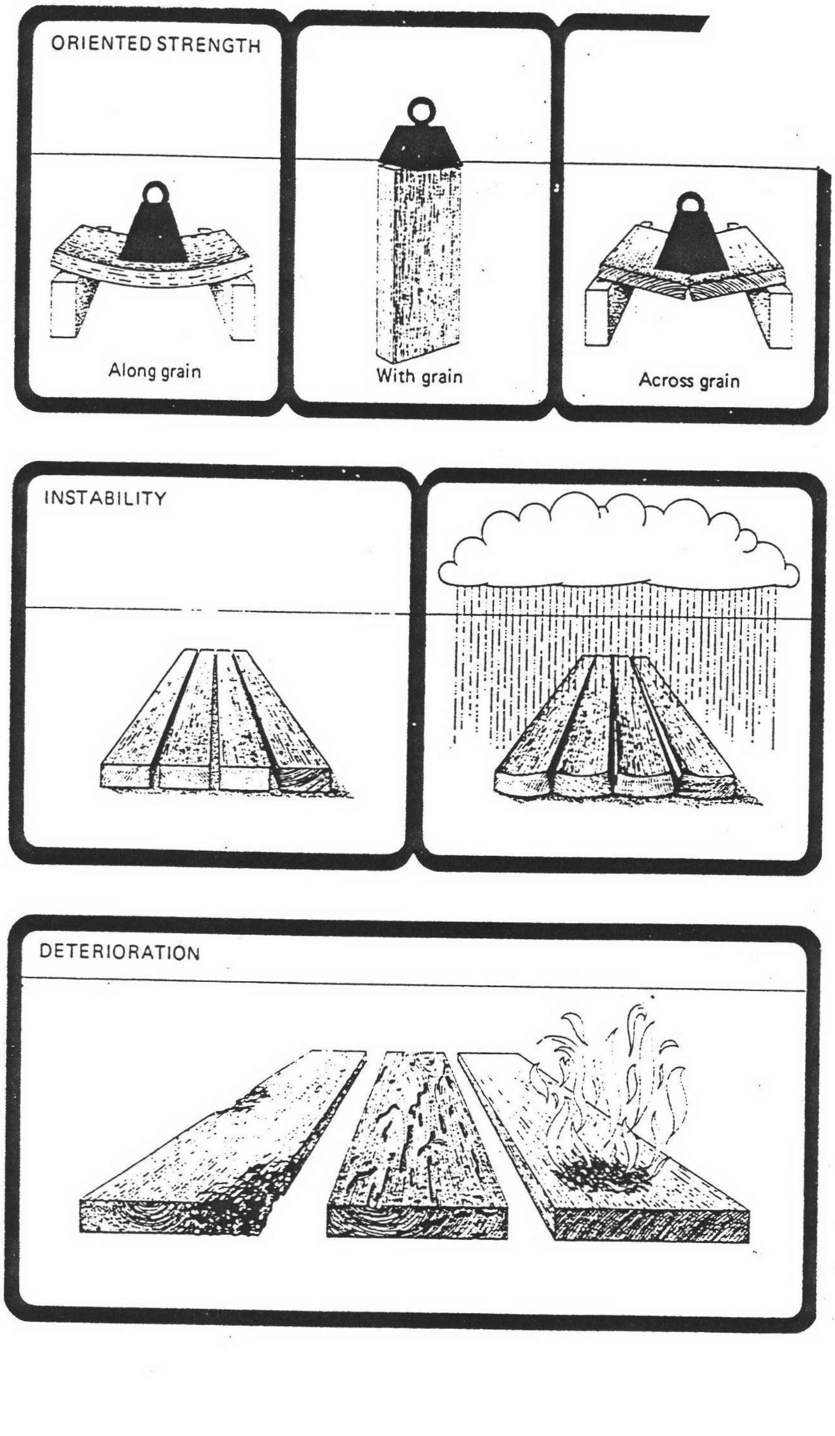

Fig. 1.7 Some of the undesirable properties of wood ; oriented strength, dimensional instability and liability to deterioration.

1.1 Background & Importance of Problem

In wood industries, it is necessary to dry the timber or veneer before bringing it into the manufacturing process, not only in furniture making but also in wooden structure. The moisture in timber or veneer has to be equal to relative humidity of air around the using area. The advantage of timber drying is as follows:

1) Drying process can make timber or veneer so durable and stable that, when it is brought to use, it will not be expanded or shrinked.

2) Dried timber or veneer is lighter and therefore cheaper to transport than green wood.

3) Dried timber is stronger and has better nail-holding power.

4) Dried timber or veneer is less liable to insect and fungal attack.

5) Dried timber is easier to be machined, painted, glued or lacquered.

6) Drying process increases strength, heat and electrical resistant.

Table 1-1 [1] show the absolute humidity of wood at stated conditions.

1.1.1 Timber Drying : Principles

Water in Wood

Moisture Content

The amount of moisture in wood is best described by the term moisture content, or sometimes moisture ratio. This is simply the weight of water contained in a sample of timber compared with the weight of woody substance. The most direct way of measuring moisture content is to weigh the sample, then oven-dry and re-weigh, the weight difference will be the weight of water it held at first.

The green moisture content, or “wetness” of freshly-sawn log, varies from species to species (Fig. 1.8). Since it is the sapwood of the living tree which carries water to the the leaves, this normally has a higher moisture content than heartwood and, contrary to popular belief, the moisture content varies only slightly through the year-even in temperature region. In those species with relatively low green moisture contents, there is very little free space within the wood cells to hold water. However, water not only lodges in the cell spaces, the lumens, but it also saturates the cell walls.

Free and Bound Water

The water in the cell lumens behaves like water in a saucer; being left under normal conditions, it slowly evaporates until the last drop has gone. Because it is not bonded to the wood in any way, that in the lumens is called "free water", and it is this which evaporates first when wood is dried. When the last drop of the free water has evaporated, any further drying must involve removal of moisture from the cell walls. However, this does not behave as free water, because the cellulose, hemicelluloses and lignin trap it chemically and physically, this water is called "bound water". Its removal during drying is more difficult, and therefore slower, than that of free water; indeed, it can only be completely driven out of the wood by extreme methods, such as oven-drying.

The precise moisture content at which wood loses all its free water but none of this bound water is called the "fibre saturation point". For nearly all timbers, this occurs at moisture contents between 24 and 30%.

Table 1-1 Moisture Content of Wood in Equilibrium with Stated Dry Bulb Temperature and Relative Humidity.

TEMP DRY-BULB		Relative humidity (percent)																			
(deg. F)	(deg. C)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	98
30	-1.11	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3	26.9
40	4.44	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3	26.9
50	10.00	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3	26.9
60	15.55	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1	26.8
70	21.11	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9	26.6
80	26.67	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6	26.3
90	32.22	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3	26.0
100	37.78	1.2	2.3	3.3	4.2	5	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9	25.6
110	43.33	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4	25.2
120	48.89	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0	24.7
130	54.44	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5	24.2
140	60.00	0.9	1.9	2.83	3.6	4.3	5.0	5.7	6.3	7.0	7.7	8.4	9.1	10.0	11.0	12.1	13.6	15.3	17.7	21.0	23.7
150	65.56	0.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4	23.1
160	71.11	0.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.3	10.3	11.4	12.7	14.4	16.7	19.9	22.5
170	76.67	0.7	1.5	2.3	3.0	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.2	9.0	9.9	11.0	12.3	14.0	16.2	19.3	21.9
180	82.22	0.7	1.4	2.1	2.8	3.5	4.1	4.7	5.3	5.9	6.5	7.1	7.8	8.6	9.5	10.5	11.8	13.5	15.7	18.7	21.3
190	87.78	0.6	1.3	1.9	2.6	3.2	3.8	4.4	5.0	5.5	6.1	6.8	7.5	8.2	9.1	10.1	11.4	13.0	15.1	18.1	20.7
200	93.33	0.5	1.1	1.7	2.4	3	3.5	4.1	4.6	5.2	5.8	6.4	7.1	7.8	8.7	9.7	10.9	12.5	14.6	17.5	20.0
210	98.89	0.5	1.0	1.6	2.1	2.7	3.2	3.8	4.3	4.9	5.4	6.0	6.7	7.4	8.3	9.2	104	12.0	14.0	16.9	19.3

(From Wood Handbook, 1974)

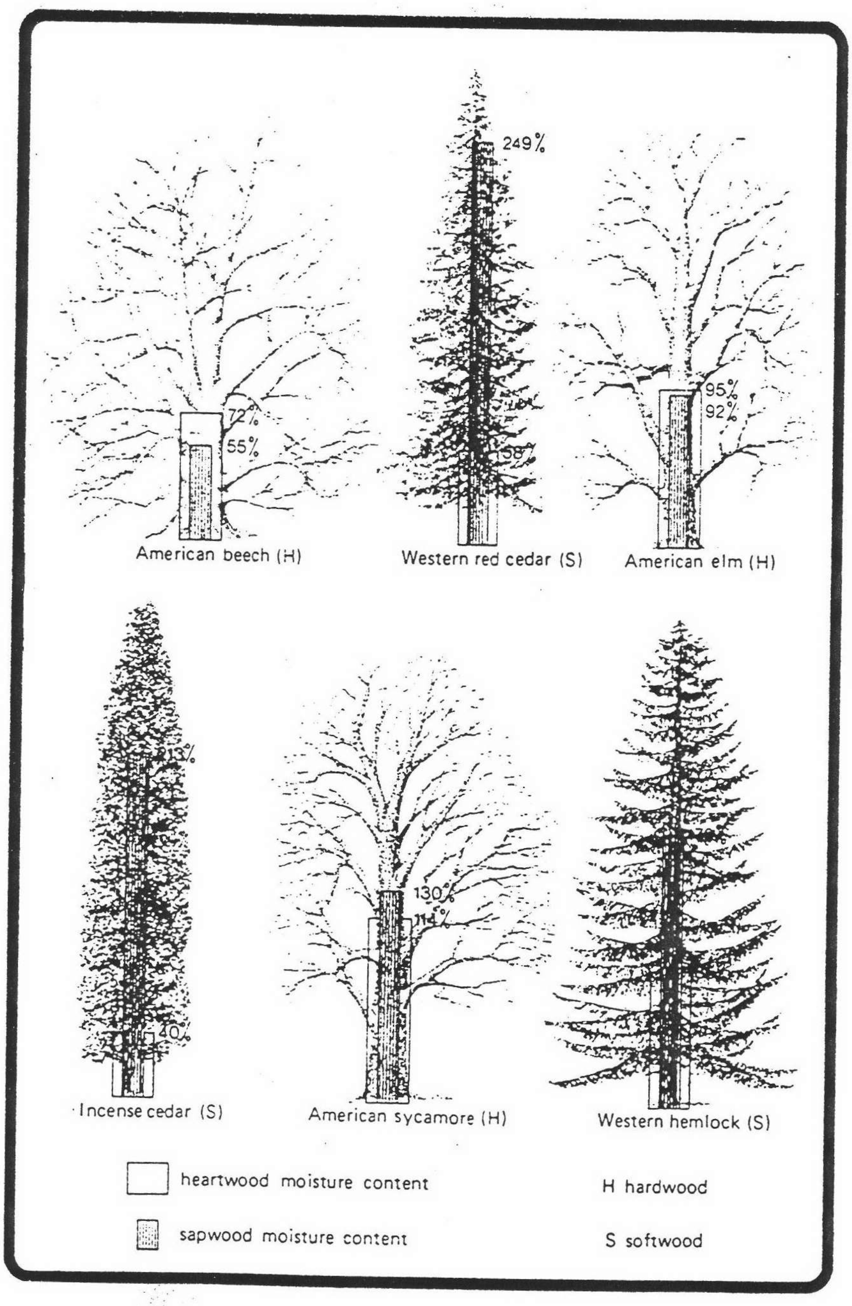

Fig. 1.8 *Typical heartwood and sapwood moisture contents for hardwoods and softwoods, showing the wide range normally found. The values given are averages; there is often considerable variation within individual trees, especially in the sapwood. Hardwoods tend to have greater moisture contents because they contain a larger proportion of hemicelluloses (the hygroscopic of the wood constituents) than softwoods.*

Drying and Its Consequences

Shrinkage of Timber

Free water is not linked to the wood structure and, its removal, therefore, causes little shrinkage of the wood. However, any change in the bound water content does change the wood dimensions; loss causes shrinkage, gain produces expansion. The sticking of doors and windows in damp weather are every day examples of this phenomenon. These changes occur spontaneously whenever the conditions of the air surrounding a piece of wood alter. The property of a substance enabling it to pick up and lose water in this way is known as hygroscopicity; the substance itself is said to be hygroscopic. When wood has dried so it no longer gains or loses moisture to the surrounding air, it is said to be at its equilibrium moisture content, or fully cried, for those particular conditions of temperature and humidity.

Rate of Drying

The factors affecting the rate at which wood dries (Fig. 1.9) are:

1. Relative humidity: this term relates the amount of water vapour in the surrounding air to the maximum. It could hold at that temperature and is expressed in a percentage. The higher the relative humidity, the lower will be the drying rate; indeed, on very humid days, wood in a drying yard may get wetter. However, even in long spells of humid weather, wood can never assume a moisture content higher than its fibre saturation point, unless wetted by liquid water.

2. Temperature: the higher the temperature, the greater will be the drying rate. However, some woods will collapse or distort if the drying temperature is too high.

3. Air movement: wood dries quickly when warm dry air continually replaces the air wetted by evaporated water from the wood.

4. Rain and snow: in climates with frequent rain or snow, wood during seasoning has to be protected by some kind of cover to prevent wetting.

5. Type of wood: some woods dry more quickly than others. The rate of drying depends on the original moisture content, the density of the wood, and its structure. If the pathways for water movement within the wood are restricted, by tyloses for example, then drying will be slower, in general, hardwoods dry more slowly than softwoods.

The rate of drying affects the quality of the dried timber, if dried without care, some defects from drying can appear, and the wood may be attacked by insects or fungi, making the timber unsuitable for further using.

1.1.2. Timber Drying : Methods

There are many ways of seasoning timber, but mainly for economic reasons, only two are in common use, air-drying and kiln-drying. Some of the less important methods, such as vapour-drying or chemical seasoning, have special applications and will not be discussed in this thesis.

Most timbers in the world are air-dried, for example, in a recent study in the U.S.A., two-thirds of the 270 wood preserving plants surveyed air-dried their stock for treatment. Many employed air-drying to the fibre saturation point, followed by kiln-drying.

The choice of drying method adopted at a timber-industrial factory depends on factors closely related to local conditions and type of product. For instance, where land values are high, a rapid turnover of valuable stock is needed, or, if the climate is continually humid, and accelerated drying method is likely to be cheaper than air-drying. However, with items such as poles (Fig. 1.10), which need specially-designed kilns, air-drying may be the most economic method unless pole treatments are the main source of income.

In this thesis, we, as its objective, have considered only the kiln drying which will be applied to the continuous drying process used in veneer dryer.

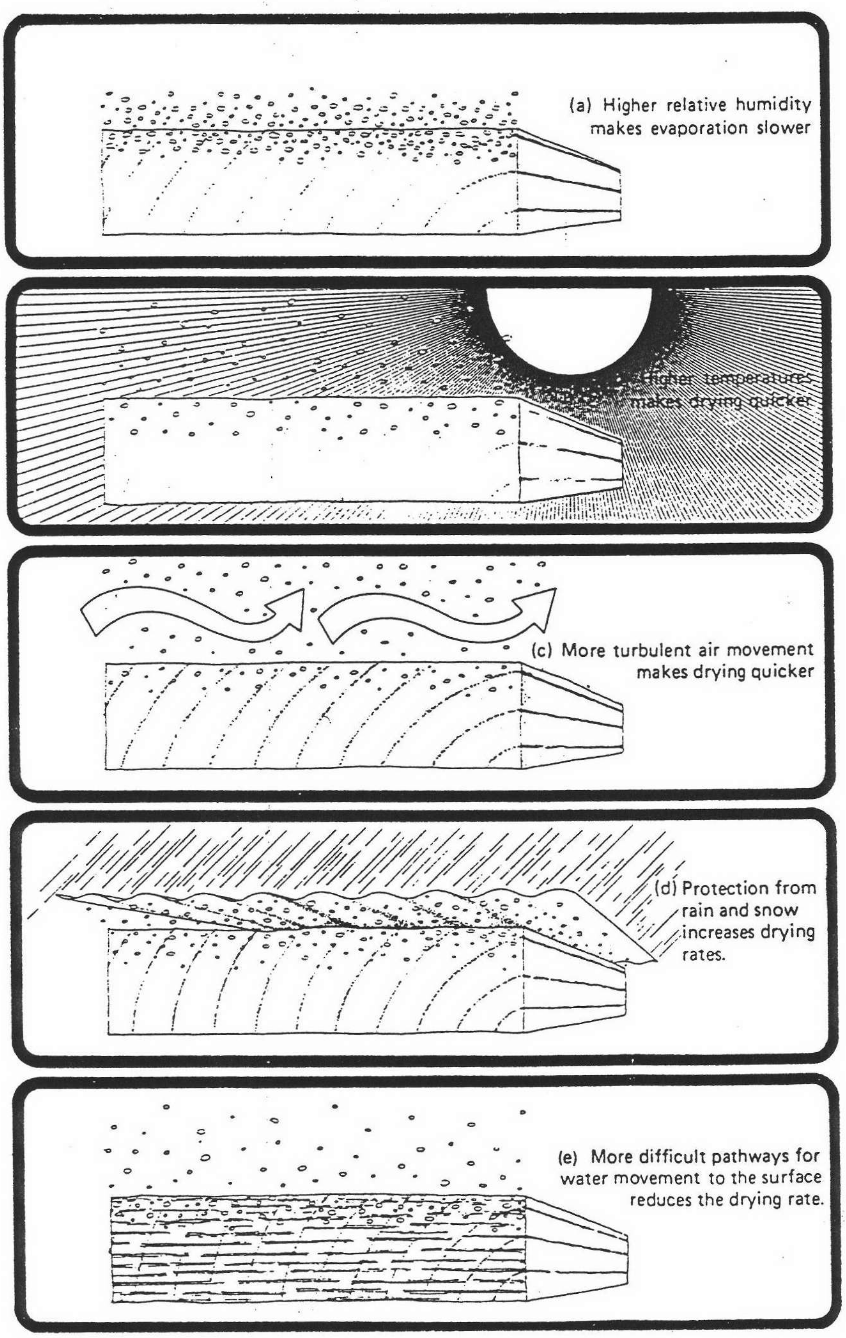

***Fig. 1.9** The rate at which wood dries depends on many factors: humidity, temperature, wind and species.*

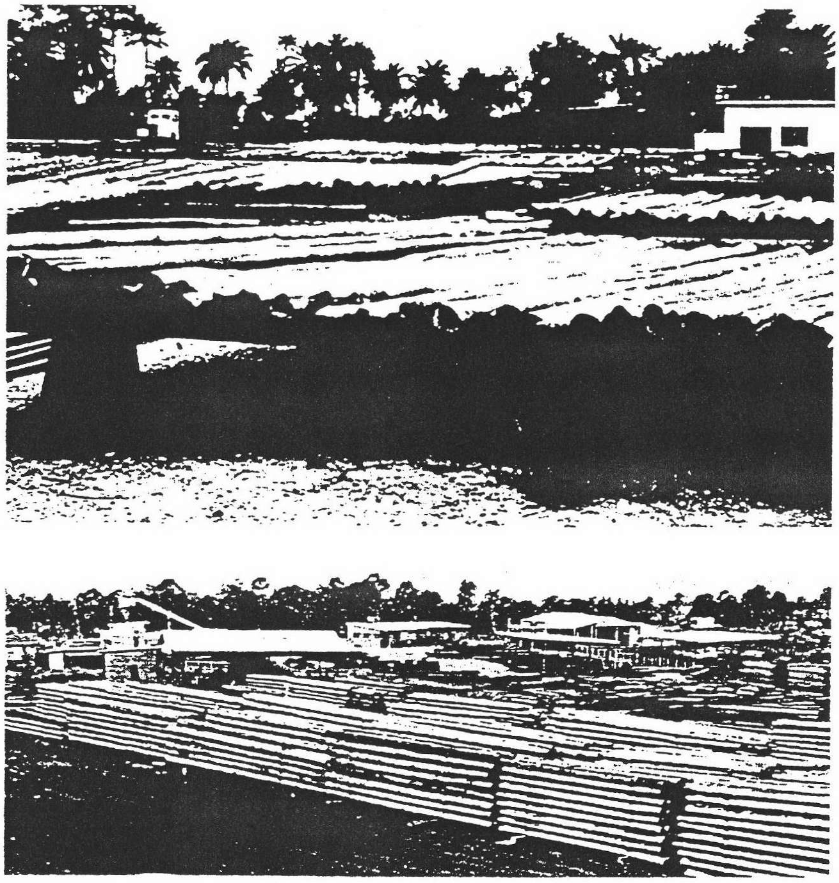

__Fig. 1.10__ Air-drying poles: (top) open (Nauclea badi) on specially-constructed racks in Nigeria. The racks are built well above the ground to allow good air ventilation around the poles. This treatment plant has a large drying area and there is no need to stack the poles more closely; (bottom) neatly stickered poles at a treatment plant in Brisbane, Australia, the stickers have all been pre-treated to avoid the risk of transferring fungal infection to the poles.

Kiln-Drying

Despite the fact that the only capital expenditure needed for air-drying is on land, stack foundations, covers and stickers, there are many disadvantages. Of these, perhaps the variability of climate is the most significant: if cold and wet, drying will be slow and may even cease, if very hot, little can be done to guard against drying defects. In some climates, such as the U.K. for example, wood can only be air-seasoned to a moisture content of 23-24% in winter and perhaps 16% in summer, this is inadequate for timber to be used in heated buildings where a moisture content of 9-12% is required.

Apart from these technical limitations, air-drying has economic disadvantages, it ties up large area of land and substantial investment capital, particularly with valuable hardwood stocks. The unpredictability of drying times complicates long-term economic planning.

Kiln-drying, in contrast, allows timber to be seasoned to any desired moisture content, in a predictable time, with the minimum of seasoning defects and at the maximum possible rate.

Principle of Drying Kilns

Essentially, a kiln is a chamber designed so that the temperature, humidity and flow of air through the timber stacks can be controlled (Fig. 1.11).

Temperature can be varied in the range 35 to 125 ^{O}C, depending on the type of kiln. Heat is usually generated by oil or wood waste.

Humidity is adjusted by introducing fresh air through vents: sometimes steam can be introduced, although this is normally only required near the end of the drying period or if timber is being reconditioned. During kilning, temperature and humidity are altered frequently to conform with the kiln-drying schedule for the species being dried. These changes are brought about manually or automatically so that, at all times, the rate of movement of moisture from inside the timber equals to the evaporation rate from the surface, thereby avoiding drying defects.

Air is circulated through the stacks by fans at suitable velocities; the fans are kept running at constant speed to maintain uniform flow. In addition, the kiln doors are made as airtight as possible and baffles are provided to prevent air from short-circuiting instead of passing through the charge. Once the air circulation system has been designed, kiln operators rarely need to adjust it; if problems of uneven drying do arise, these are often due to poor stack construction. Indeed, even with perfectly-controlled air conditions, a badly constructed charge will almost certainly degrade.

As with air-drying, it is important to monitor the progress of drying: this is normally done by the periodic weighing of sample boards placed throughout the stack, which have been checked for moisture content at the beginning of the run (Section 2.1). Time switched are provided on most modern kilns which automatically reverse the air-flow to improve the uniformity of drying.

As it is known that drying is the important process to reduce the moisture content in wood to equilibrium condition which can made the timber to be more quality and durable. Normally in small factories, there is no any kind of kiln dryer but they use the method called "air drying" which uses sun's heat and atmospheric air current to extract moisture from timber stacked and exposed to ambient conditions. Though the air drying process is the most economical but there will be so many problems occurred such as in furniture making, the moisture content reduced is not enough for suitable condition, the color of timber is changed and the timber is often deformed. Also this process takes a long period that obstructs the production plan. In Thailand, the appropriate moisture content of timber brought to make furniture is about 11-12 % (dry basis) and for exported timber, it is about 6-10 % (dry basis) [1] which the natural drying process cannot achieve the value. The important one of problem occurred in open air drying process is the difficulty of controlling moisture and temperature.

Kiln dryer is one which can make the lower moisture content required and it takes less time than open air drying process.

The principles of good drying process are as follows:-

1) Using drying period as short as possible;
2) Giving uniform value of moisture content;
3) Having no residual stress in wood;
4) No defection occurred during drying process;
5) Not reduce mechanical properties of wood.

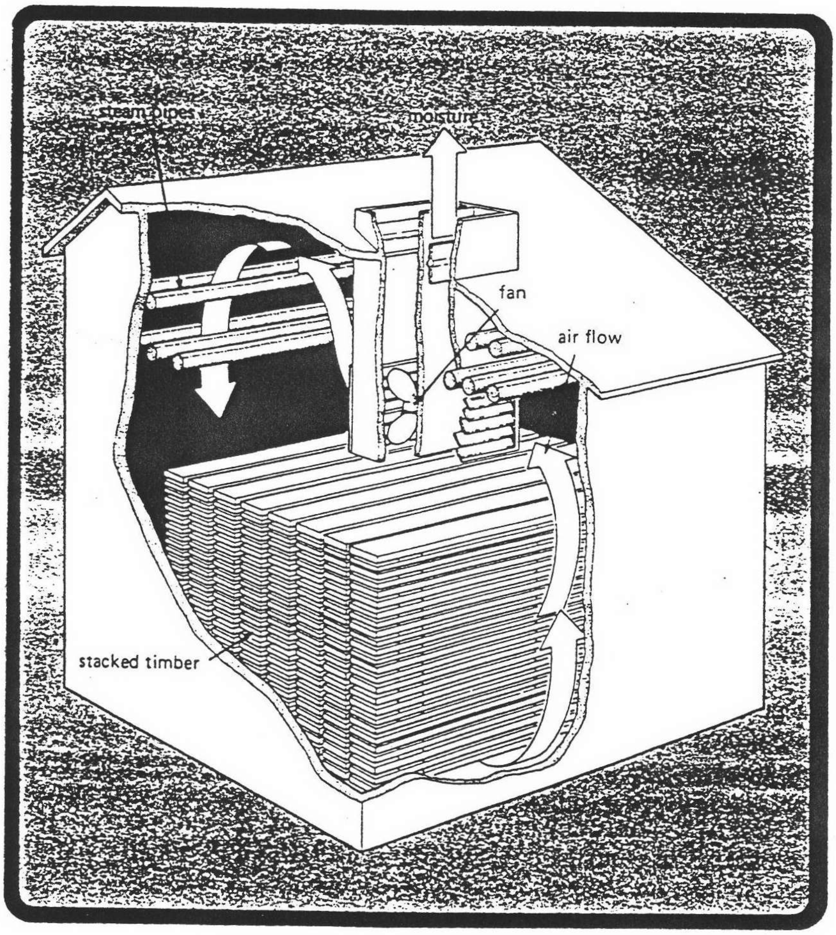

Fig. 1.11 Principles of a conventional kiln with overhead fan to accelerate air flow. Heat comes from steam-heated coils over which the air passes before it moves through the stack. Moisture is removed through a vent in the roof.

Wood veneer is one of raw materials in wood industry. It is used in, for example, plywood manufacturing by compressing many sheets of veneer and applying glue so that they will be sticked together. It is also used in furniture making, some parts of tables or chairs are made from wood veneers in the same process as plywood manufacturing. But in this case, the veneers are cut and bent to the required pattern.

Normally, newly veneer contains moisture much in excess of the amount permissible for manufacturing process. In practice, it is found that veneer is not in a suitable condition for manufacturing until the free moisture and part of bound moisture has been removed, and the amount that should be allowed to remain in order to achieve the best results will depend upon the condition of service for which the veneer is intended.

Veneer will expand and contract as its moisture content increase and decrease respectively. Given sufficient time, a piece of veneer will reach and equilibrium moisture content, depending on ambient temperature and relative humidity. If veneer with moisture making, it will dried out later and the resulting shrinkage will cause splitting, part-peeling and other damages.

1.1.3 Veneer Drying : Method

In this thesis, study is focused on furniture making industry. Veneers commonly used in this industry are generally small size (300 x 500 mm.). Being small and thin the veneer under-go some wavy deformation during drying process which is not suitable for the furniture making industry. Such wavy problem seldom occurs in plywood manufacturing or even if it happens, the scale of deformation will be very small since the weight and mass of plywood is much more than the veneer.

At present, most of the furniture making industries in Thailand still operate the drying process by means of drying room to reduce the moisture content of veneers. They keep the veneers in sheltering form (Fig. 1.12), and leave them in the drying room for a period, applying steam into the drying room and check moisture content to be as required. However, though this method is good in the way that it can dry large number of veneer sheets as much as the size of the room, the problem of this method is that some veneers will be waved and cracked due to free shrinkage. Other disadvantage of this method is that it takes a long time by average of 24 hours; moreover it takes much workmanship to transport veneer sheets in and out of the drying room. Some factories have limited area or floor to build the large drying room so they cannot increase their production as they need.

To get rid of these problems, we need the most practical and commercial dryer that;

1) Can reduce the wavy veneers and crack as much as possible,
2) Can give the specified moisture content,
3) Has capacity to dry the veneers at least not less than the old drying room,
4) Does not require a large area or floor in process,
5) Takes a short period to dry the veneers to specified moisture content,
6) Reduces workmanship in manufacturing process.

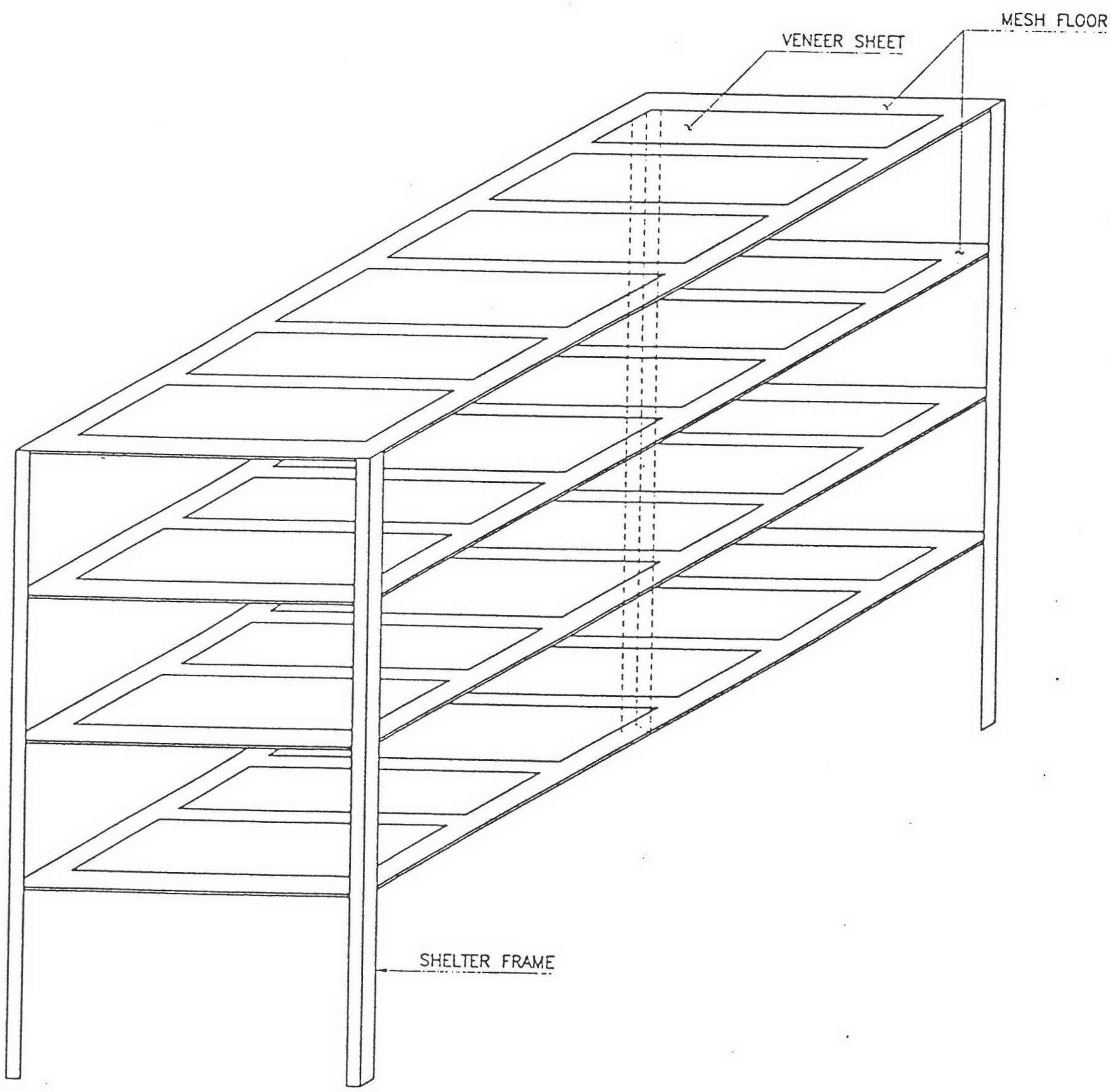

***Fig. 1.12** Veneer sheets are dried in the drying room by sheltering form*

For solving of these problems, the continuous dryer is the most practicable and commercial one. This type of dryer uses many roller to convey the veneers through the dryer. The veneers are fed by driving roller which is driven by electric motor. Heat used to evaporate moisture in veneer is supplied from hot air unit connected to the dryer by piping. To increase the heat transfer efficiency by uniform temperature gradient whole throughout the dryer, the electric fan is brought to circulate air inside the dryer. In principle of workmanship problem, this dryer need only two persons to put in and take off the veneers at front and end of conveyor respectively. The dryer can be designed to have size and capacity enough for production planning. At least we can adjust the speed or increase the steam temperature to increase or decrease the production capacity.

In the problem of wavy veneers and crack, the veneers will be pressed together with heat making veneers smooth and not allowing it to free shrink to get rid of cracked veneer.

Almost of the problems indicated above can be solved by engineering design of speed of conveyor and steam capacity not only in workmanship principle but also in the required period of time. If the length of dryer designed by space area of factory is not enough for production capacity, it can be designed to be the form of leveling. The second level bring the veneer in the opposite way of conveyor and, if necessary, the third and so on can be added.

Principle of Continuous Dryer

As conventional kiln dryer, continuous dryer is also a chamber designed that the temperature, humidity and air circulation in the chamber can be controlled.

Transportation of veneer is by belt conveyor for the small thickness and by roller conveyor for bigger thickness. Veneer sheet with small thickness is always easily reached a certain degree in drying and become fragile, so it has to be conveyed by the metallic belts, having a much more gentle pressing action and avoiding the splitting of the material. On the other hand, veneer sheet with bigger thickness is transported by roller conveyor which a strengthening press effect is obtained on the sheets.

The velocity of transportation can be varied by adjusting speed of electric motor.

Temperature in drying chamber can be varied according to type and thickness of veneer. Specially for new technological continuous dryer, the temperature is automatically controlled by sets of temperature sensors that activate heating media regulating valve or electric fan.

Moist air will be transferred by means of blower. Two damper are installed to allow air circulation and controlled by humidity measuring device. The damper will be automatically operated according to the set points.

However, this type of dryer is not practicable for small factory because it is usually heated by electricity, oil or gas. All of which are expensive form of energy. It is also required close control of humidity and drying temperature to ensure that the veneer will not dry too quickly which may cause cracking and other degradation dryer. But in the large factory which have high production rate, the profit the factory can get is worthwhile comparing to the expense of the energy consumption. It is important for the owner to do the workstudy before using which kind of dryer.

1.2 Literature Review

The previous study of wood veneer drying has not been distributed to public because all of the experiments are made by manufacturer in order to develop such kiln dryer for its own use. All the data and results has been kept secret by each manufacturer. However, we can take a lot of information in solar kiln drying method of which the energy and moisture balance equations could be applied and used with veneer dryer. Therefore, in this chapter various studies of timber kiln drying are summarized as follows:-

Wengert, E.M. (1971) described the timber dryer at Colorado State University with following specification: translucent walls; monopitch 17 deg. roof, facing south; plywood door at the back wall; concrete floor; every wall is opening for ventilation and electric fax gives 1.4 m/s air velocity evenly through the load. Five modes of energy loss accounted for 84% of the incoming energy. These were:-

1) Convection from kiln fabric	29%
2) Outgoing heat energy	17%
3) Ventilation	14%
4) Net long wave radiation	13%
5) Conduction through floor	11%

The remaining 16% of heat energy accounted for heat energy needed to dry the wood and other minor losses. Suggestions to reduce the above loosed are as follows:-

a) Reduction of convection losses from the kiln fabric by using double layers of translucent material;

b) Pay close attention to the ventilation design and placement to avoid venting warm dry air;

c) Losses by longwave radiation are difficult to reduce but the use of double layers wall and coated with infra-red reflecting chemical is suggested;

d) Pay close attention to the insulation of kiln floor, the usual concrete slab being poorly insulated.

Skarr, C. (1977) discussed the energy requirement for drying timber. He concluded that kiln drying uses between 2-2.5 times the intrinsic energy required to evaporate water and the traditional greenhouse type solar dryer uses six times the solar energy needed to evaporate the water. A typical examples of energy requirement for kiln drying of maple timber are given as follows:-

Energy Component	**% of total**
heating moist wood	4.0
heat of sorption	0.9
evaporation of water	45.3
heat and humidification of vent air	16.7
replacement of heat loss	33.1

Helmer, W.A., et al. (1980) described solar energy collection and dehumidification with heat pump. A computer simulation model was developed to predict the performance of a combined solar dehumidifier and wood drying system. When input parameters of solar collector, drying chamber, wood and dehumidifier characteristics, and ambient weather condition (dry/wet bulb temperature and solar radiation) were known, the model was used to predict the wood moisture content, air temperature and humidity, and energy consumption at any time during the drying process. The computer-simulation model accurately predicted the kiln dry bulb temperature, kiln relative humidity and wood moisture content for the operation of and existing solar wood dryer. The results were later used to predict performance of the 1.2 m^3 air solar collector. The kiln ventilation was controlled so that the vent fans would turn on whenever the relative humidity exceed the maximum set value of the following schedule:

R.H. maximum (%)	Moisture Content (%)
80	> 50
75	40
65	35
50	30
35	25
20	< 25

The results indicated that the model was sufficiently accurate to predict wood drying time when using solar energy as the only heat source for the kiln.

Steinmann, D.E., Vermaas, M.F. and Forrer, J. B. (1980) reported that more efficient control of temperature, air circulation and especially relative humidity are required to effectively operate solar timber dryer. The solar heated timber dryer was of the external collector type with forced air transfer system.. Air circulation was provided by two fans and air intake was provided by a centrifugal blower. Outlet vents were placed on the pressure side of the fans and butterfly valves were operated to synchronize with the blowers on the inlet vents. Temperature compensated equilibrium moisture content sensors were used to monitor solar collector conditions, with and without kiln attached. The primary objective of the work was the development of a microprocessor-based data capture and control system for a solar kiln, which would follow a given drying schedule and adjust it according to current weather conditions and moisture content. The solar kiln was used experimentally to compare solar drying with the air seasoning of matched load of Pinus radiata timber. It was decided to concentrate on equilibrium moisture content as the control parameter. The data acquisition system and recorded the following parameters on magnetic tape:

i) mass of the solar kiln load;
ii) mass of the air dryer load;
iii) air temperature inside the kiln;
iv) air temperature outside the kiln;
v) relative humidity of the air inside the kiln;
vi) relative humidity of the outside the kiln;
vii) status of valve (open or closed);
viii) solar radiation on test site;
ix) time of day;
x) a predetermined value for the calculated oven dried mass of the load was required for calculating the moisture content of the wood; The oven dried value could be updated as required from moisture meter measurements below fibres saturation point.

Drying started in winter with both system loads with timber at initial moisture content of 93% dry basis. After 16 days, the air dryer and solar kiln load were unloaded with final moisture content lower down to 23% and 12% dry basis respectively. The drying rate in the solar kiln was always higher than that of the air dryer, except from the 3rd to the 5th day, when strong wind was blowing and drying rate were equal.

Kayihan, F. and Stanish, M. A. (1984) described movement of free water, bound water and water vapor together with heat conduction under the constraint of local thermodynamic equilibrium. The general mathematical model consisted of four partial differential equations, one for thermal diffusion and three for diffusion of each of the water phase-coupled with nonlinear algebraic equation for the local equilibrium condition. The equations for free and for bound water diffusion could be combined and the resulting three partial differential equations transformed into the spatial coordinates into discrete compartments while retaining time as a continuous variable. The differential transport equations coupled with algebraic equilibrium constraints could then be solved in a sequential iterative manner. Evaluation of the model using experimental drying rate measurements showed that for a small particles of about 6 mm. thickness such as sawdust, the simulation closely matched the drying behavior observed for other different particle sizes, temperature and initial moisture contents. For larger thicker material of about 25 mm. thickness such as flakes, the agreement between model simulation and experimental data was less satisfactory. The heat of vaporization of moisture, h_{fg} (kJ/kg) and the equilibrium moisture content, dry basis, U_e were also introduced as follows:-

$$h_{fg} = 267\,(6477 - T_A)^{0.38}\left[1 + 0.4\left(1 + \frac{U_d}{0.3}\right)\right], \quad U_d < 0.3$$

$$U_e = \frac{18}{W} a_2 H \left[\frac{1}{f_1} + \frac{a_1}{f_2}\right]$$

where

$$W = 5.72 \times 10^{-3}\, T_F^{2} + 1.961 \times 10^{-2}\, T_F = 216.9$$

$$a_1 = -1.547 \times 10^{-4}\, T_F^{2} + 3.642 \times 10^{-2}\, T_F + 3.73$$

$$a_2 = -1.714 \times 10\text{-}6\, T_F^{2} + 1.0533 \times 10^{-3}\, T_F + 0.647$$

$$f_1 = 1 - a_2 H$$

$$f_2 = 1 + a_1 a_2 H$$

$$H = \frac{1}{2}\left[Z_1 + \left(Z_1^{2} + \frac{4}{a_1 a_2^{2}}\right) 1/2\right]$$

$$Z_1 = \frac{(1 - Z_2)}{a_2} - \frac{(1 + Z_2)}{a_1 a_2}$$

$$Z_2 = \frac{18}{WU_{e(i)}}$$

where

U_d = the total moisture content in dry basis

H = relative humidity

T_A = absolute temperature, (K)

T_F = dry bulb temperature (^oF)

Taylor, K.J. & Weir, A.D. (1984) described the performance of a glasshouse type solar timber dryer by using numerical simulation and experimental measurement. The sloping roof and three of the walls of the solar kiln at Nasinu, Fiji, were made of glass window panels mounted of a light wooden frames. The roof faced north (equatorward), at a slope equal to the latitude (18^{o}S). The rear was made of wooden planks and incorporated double doors which will be opened when transferring the timber load, but otherwise kept closed. The timber stack to be dried was placed on a railway trolley and wheeled into place. The doors were lined of the inside with aluminum insulation paper to help retain heat inside. Air was circulated within the kiln by a 700 watt electric powered fax. To help direct the air flow horizontally through the timber stack, there was a wall of concrete "breeze blocks" on both sides of the stack. Above the stack was a galvanized iron false ceiling, with a vertical baffle running down the middle of the kiln and above it to ensure that the air flow will not by-pass the timber stack. All surfaces, including the concrete, were painted black. Moist air was to be removed from the kiln by via four small vents in the rear wall. The experimental results reported the capability of the solar kiln in drying about 5 m^3 of timber, from green to equilibrium, within about 3 weeks. A fairly simple model gave a reasonable result for fitting the drying curves. It was found that the capacity but with high rate of forced air circulation through the timber stack. The moisture movement coefficient, K (m/hr) and the specific heat of timber, $C_{p, t}$ (kJ/kg K) were also introduced as shows below:

$$K(d, T) = K_o \frac{X_s(T)}{X_s(T_o)} \frac{(d_o)}{(d_T)}$$

$$C_{p,t} = \frac{(4.18\, U + 1.25)}{1 + U} + 0.17$$

$$\frac{dU}{dt} = \frac{K(U - U_e)}{x}$$

$$V_d \left(\frac{dX_i}{dt}\right) = -Q(X_i - X_a) - m_o \left(\frac{dU}{dt}\right)$$

where

$\frac{dU}{dt}$ = the rate of water movement, (%/hr)

x = thickness of timber, (m)

U = moisture content, (% dry basis)

U_e = equilibrium moisture content, (% dry basis)

K_o = the moisture movement coefficient of mahogany 1.4×10^{-4}

$X_s(T)$ = absolute humidity at saturation, (kgw/m^3)

$X_s(T_o)$ = absolute humidity at saturation for 30 ^oC, (kgw/m^3)

X_i = absolute humidity inside solar kiln, (kgw/m^3)

X_a = absolute humidity at ambient conditions, (kgw/m^3)

d_o = timber density of mahogany at 30 ^oC = 440, (kgw/m^3)

d_T = timber density at local temperature, ((kgw/m^3)

V_d = volume of the kiln, (m^3)

Q = volumetric flow rate of air into and out of the kiln, (m^3/s)

m_o = oven dry weight of timber, (kg)

Ploypai, W. (1987) described the solar timber dryer used at Sakol Nakorn, Thailand. The flat plate collector area was 34.2 m^2 and tilted 17^0 from the horizontal floor. Air circulation in the drying chamber was induced by a 30" fan, while air circulation between the drying chamber and the collector was induced through two 16" fans. First experimental results indicated that moisture content of 1.33 m^3 of Pterocarpus macrocarpus (Pradoo) and Afzelia xylocarpa (Ma-Ka) timber were reduced from 25 % to 12 % (dry basis moisture content) in 11 days for solar kiln drying and 26 days for open air drying. Second experiment use 2.0 m^3 of Eucalyptus camaldulensis and Meliazedarach timber with moisture content reduced from 30 % to 12 % (dry basis moisture content) in 11 days for solar kiln drying and 36 days for open air drying.

1.3 Scope of Study

In the past studies have only been done on timber drying with different heat sources. Veneer drying, especially in furniture making industry, has never been researched before. Therefore, the scope of study is to observe and study the characteristic phenomenon of veneer drying process and all important parameters which effecting the process.

However, the topic of the study has been selected base on the availability of raw material and equipment for the process.

1.3.1)

- Heat energy used in the kiln dryer is from LPG Air heater

- Working fluid is hot air circulated by electric fan.
- Using rolling conveyor to convey the veneers through the dryer driven electric motor.
- The dryer can reduce man power in operating compared to the lod drying room.
- The dryer can reduce working area by compact packaged design.
- The dryer can reduce wavy veneer to be nearly zero.
- The dryer can reduce crack percentage of veneer to be nearly zero.

1.3.2)

The properties of veneer used in drying is as follows:

- Use parawood veneer and size of 250 x 250 mm.
- The initial property of veneer is green-fresh and the required moisture content after drying is 8 %
- The thickness of veneers is specified to be 1.5 and 2 mm.
- The quality and properties of veneer after drying is specially propriate to furniture making, i.e., no waviness.

1.4 Objective

1.4.1) To study continuous drying process of veneer with specified thickness in specially purpose of furniture making.

1.4.2) To study the important parameters that effect to the process which is relative to humidity of hot air stream, speed of hot air stream, temperature of hot air, thickness of veneer and resident time.

1.4.3) Construct the model of kiln dryer to test and find the relations of the parameters mentioned above.

1.5 Anticipated Benefits

1.5.1) To know characteristic phenomenon of wood veneer drying.

1.5.2) To know the factors or parameters that affect the drying process, also their influence on physical properties of veneer.

1.5.3) To know how those parameters are related to each others which could be useful in design of continuous type dryer.

1.5.4) To know the possibility of using this type of dryer in industry and improve wood veneer drying process of Thai Industry.

1.6 Steps of Experiment

1.6.1) To study and research the concerned data and theory from text book, journal or some old research documents, then define the parameters and factors those are the pattern of dryer.

1.6.2) To study and analyze the mathematical model or the empirical equation of the dryer.

1.6.3) To construct a model dryer.

1.6.4) Test the model by actually drying the sample veneers of proper sizes. Record experimental data both of veneers and dryer such as dry bulb and wet bulb temperature inside and outside of the dryer, air speed, speed of conveyor, air ventilation data and moisture content of veneers, etc.,.

1.6.5) Analyze all data to determine the empirical formula of the dryer for predict or use in such drying conditions.