Construction and Operation of Solar Kilns for Seasoning Timber in Bangladesh

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ABSTRACT

The paper describes the need to develop an inexpensive and simple technique for seasoning timber in Bangladesh. The theory and design principles of solar kilns are discussed. The details of construction and operation are also described. The performance of a solar kiln erected at the Bangladesh Forest Research Institute is discussed in respect of attainable temperature, drying time and quality of dried timber. The paper also provides information about the basic economics of operating such a solar kiln in Bangladesh.

INTRODUCTION

Seasoning ensures the economic utilization of wood. It imparts improved physico-mechanical properties, offers dimensional stability, increases resistance to decay fungi and reduces the physical degradation of wood. Seasoning, thus, enhances the service life of wood products. There is a growing awareness among many wood using industries in the country of this technology. But lack of adequate facilities and technical expertise force them to use, in almost all cases, unseasoned or partially dried timber.

There are various methods for seasoning timber. Among them the air drying is the simplest and cheapest. It involves only stacking of timber in the direct sun or under a shed. The main drawbacks of this method are: it takes a long time to dry; drying cannot be achieved to the desired lower level of moisture content throughout the year; it involves maintaining large inventories of timber and also large amounts of space; wood destroying fungi and insects, which may subsequently attack the products during use, are not killed.

Steam-heated kiln drying is the widely practised commercial method. It is efficient, but expensive and complicated to install and operate. A substantial amount of heat is required in this kiln for heating and humidification. It is thus beyond the means of small to medium scale industries of the country.

The situation calls for adopting a simple and inexpensive technique which should be comparatively fast and effective throughout the year. Solar drying has been found to solve the problem. Further, substitution of traditional sources of energy like coal, oil, gas, electricity or wood-waste needed for kiln drying with a free and inexhaustible source of solar radiation used in solar drying also helps to conserve the country's valuable fuel stocks.

CLIMATE AND SOLAR RADIATION

Bangladesh lies between 21° and 27°N latitude with generally low elevation. During the summer, the ambient temperature varies from 30° to 35°C and relative humidity ranges from 85% to 95% while in the winter the temperature fluctuates from 16° to 27°C and relative humidity varies from 50% to 75%. Variation of temperature from 27° to 32°C and relative humidity from 75% to 90% are common during the other seasons of the year.

The amount of solar radiation that reaches the earth depends mainly on the latitude of the locality, the declination of the sun and the hour of the day. Averaged over the entire year, some of the poor sites may receive less than 3 kWh per m^2 per day while the better sites may receive over 5 kWh per m^2 per day (Tschernitz and Simpson, 1977). Bangladesh falls in the better areas. It gets abundant solar radiation throughout the year in all parts of the country (Hussain, 1984).

THEORETICAL CONSIDERATIONS/PRINCIPLES OF OPERATION

Solar kilns may be defined as totally enclosed structures in which timber is dried by deriving energy from solar radiation with the help of a heat absorber. A transparent or translucent glazing material is used as a cover over an absorbing body. It creates a greenhouse effect. The short wave solar radiation passes through the glazing material. A heat absorber inside the kiln generally of flat plate type, made of black metal or other materials, absorbs the solar radiation, gets heated, and subsequently emits heat as long wave radiation. The glazing material is opaque to this radiation and thus heat is trapped. The heat is transferred to the air flow created by blower fans. The hot air picks up moisture evaporated from the timber. Some of the wet air is vented out through the exhaust vent and fresh air is vented in.

During the drying process solar kilns get energy primarily from solar heating panels. The air flowing in through the inlet vents and the electric fans also contribute to the energy input. Heat utilized in warming the wood, overcoming hygroscopic attraction and evaporating water from the wood surfaces is useful heat. The heat loss due to air leaving the outlet vent is the direct loss. Heat is also lost by radiation, conduction and convection. The heat absorber panel is the only significant source of losses by radiation. Losses by conduction and convection occur through the walls, roof and floor.

DEVELOPMENT AND DESIGN PRINCIPLE

A large number of solar kilns have been constructed in different parts of the world during the last two decades (Aleon 1979, Banks 1970, Campbell and Stevenson 1976, Casin et al 1969, Chen 1981, Gough 1977, Harpole 1988, Lumley and Choong 1979, Plumptre 1979, 1983, Sharma et al 1972, Simpson and Tschernitz 1984, Tschernitz and Simpson 1977, Wengert 1971, 1980, Yang 1980). All these kilns are of such different sizes and designs that it is not possible to make direct comparisons to derive exact solar kiln specifications. It is therefore, necessary for research institutions to undertake their own research to develop solar kilns to suit the local conditions of the country. Recognising this fact, the Bangladesh Forest Research Institute (BFRI) has been studying the subject since 1969 (Sattar, 1969). A solar heated timber kiln of greenhouse type has been designed and constructed at BFRI (Sattar 1982a, 1982b). Different species of various dimensions have been dried throughout the year for both research and commercial purposes. There has been an encouraging response to this new technology among the wood-using industries in Bangladesh. Fifteen such solar kilns of different sizes have been installed by both private and public wood industries in different locations of the country. Timber is being dried for making various end products, like furniture, joinery, construction, cross-arms and other uses (Sattar 1988).

The present solar kiln is a slightly modified version of the original model. It is of semi-greenhouse type. The roof and the east, west and south walls are glazed but the north wall is insulated to reduce heat loss. A corrugated plate heat collector is incorporated beneath the roof which is inclined towards the south. Two vents control the humidity and a blower fan circulates the air inside the solar kiln. The whole structure is a simple wooden frame which can be made with minimum cost and effort. The main consideration in designing this type of solar kiln is to provide a technique for the small to medium scale wood-based industries which is simple and cheap to construct and operate, and is effective throughout the year. This is important for a developing country like Bangladesh where large investment is not forthcoming and skilled manpower is not generally available.

CONSTRUCTION OF THE SOLAR KILN

The details of construction for such a solar kiln are given below. Schematic diagrams for constructing a 3.5 m^3 capacity solar kiln are shown in Figs. 1 and 2. The capacity of the solar kiln may be increased by increasing the length or width, or both. Batteries of such kilns may be erected if a large volume of timber needs to be handled.

a. The solar kiln has a simple wooden frame structure. Separate wooden frames may be made for the four sides and for the roof. These frames may then be joined and grouted into a concrete floor.
b. Glass sheets, 3-4 mm thick, are used for the three walls. Transparent polythene sheet, 0.20 - 0.25 mm thick, may be used instead of glass. The main drawback of the polythene is that it deteriorates quickly under exposure to ultraviolet light and does not last for more than 6-9 months.
c. For the reduction of heat loss, the northern wall is made of plywood. The outside of this wall is protected from rain by thin iron sheets painted with grey enamel paint.
d. Glass sheets, 5 - 6 mm thick, are used for the roof. Other glazing materials like fiberglass, polyvinyl fluoride or polyvinyl chloride may be used. But these imported materials are very expensive compared to local glass sheets.
e. The roof should be inclined towards the south at an angle equal to the latitude of the locality, i.e., 22.5° for Chittagong. This ensures maximum absorption of solar radiation throughout the year.
f. The floor is made of cement concrete. It may be painted with some enamel paint to prevent moisture entering the kiln from the ground below.
g. Corrugated iron sheet, painted matt black on the top, should be fixed beneath the glass roof to absorb solar radiation.
h. One blower fan of 0.6 m diameter with aluminium blades should be installed inside the kiln for air circulation. The fan shaft has to be fitted to a secured frame. An electric motor of 373 to 746 watt rating should be used with V-belt and pulley to run the fan at about 700 rpm.
i. Two vents, one inlet and one outlet, are provided for the control of humidity inside the solar kiln. The vents, each about 0.2 m x 0.3 m, should be located on the southern and northern walls.
j. The solar kiln should be installed on a dry site without shading by nearby buildings or trees, and where day long sunshine is available.
k. Care should be taken in the construction so that the solar kiln chamber is well sealed. It should be built so that no rainwater can enter, and the hot air inside cannot escape except through the vents.

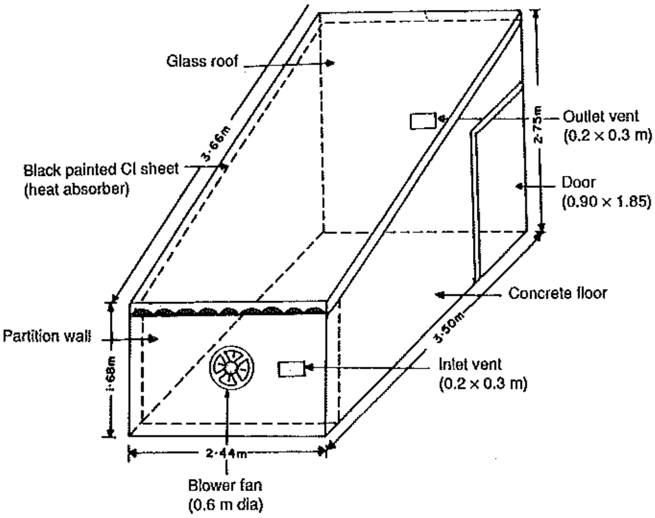

Fig. 1. Front view of 3.5 m³ solar kiln.

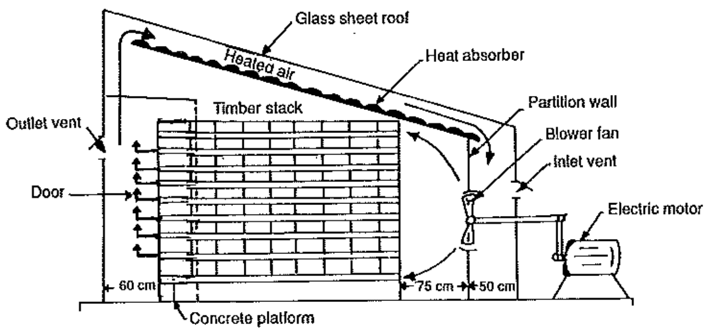

Fig. 2. Side view of 3.5 m³ solar kiln (arrows indicate the direction of air flow).

OPERATION OF THE SOLAR KILN

a. Timber should be stacked properly between 2.5 x 2.5 cm stickers to allow circulation of heated air inside the timber stack. Box type piling method should be followed to fit neatly into the kiln chamber. If the stack does not fill the chamber, spaces all round should be closed with a baffle to stop the air flow from by-passing the stack.

b. The timber stack has to be made at least 75 cm away from the blower fan to bring all the timber under the flow of the circulating hot air.

c. If timber of assorted dimension is used the thicker timber should be stacked below the thinner timber so as to facilitate the unloading of the latter which gets dried first.
d. One blower fan is sufficient for a solar kiln of 3.5 to 5 m^3 capacity. If a solar kiln of higher capacity is erected, more than one fan should be used depending on the size of the kiln.
e. The fan should be started as soon as the sun rises and should continue operating till sunset. It has to be operated continuously during the day time to utilize the maximum heat of the solar radiation.
f. The hot air inside the kiln chamber absorbs water from the wet timber in the process of drying. When this air gets saturated with water vapor the drying process will stop, and consequently the saturated air needs to be let out to allow fresh air to come in. For this purpose, inlet and outlet vents should be used.
g. During the initial period of 3-5 days, both the inlet and outlet vents have to be opened four times a day for about 15-30 minutes at 8.00 am, 11.00 am, 1.00 pm and 4.00 pm.
During the next period of 3-5 days, the vents have to be opened there times a day for about 15-30 minutes at 9.00 am, 12.00 noon and 3.00 pm.
During the subsequent period, the vents have to be opened twice a day for about 15-30 minutes at 10.00 am and 2.00 pm. This process should be continued till the timber dries properly, i.e. the moisture content of the timber reaches 12-14%.
h. The solar kiln should be maintained in good condition at all times. The outer sheathing, especially the glass roof, should be cleaned regularly for maximum transmission of the solar radiation into the kiln.

PERFORMANCE OF THE SOLAR KILN

Kiln Temperature

The temperature inside the solar kiln remains considerably higher than the ambient temperature. The solar kiln attains the maximum temperatures of 57° to 66°C against the atmospheric temperatures of 31° to 35°C between 12 noon and 2.00 pm on clear days (Sattar 1987). Even on cloudy days, the kiln can absorb intermittent sunlight and diffuse radiation for maintaining lower humidity and higher temperature than ambient conditions. During the night the temperature of the kiln is found to exceed the ambient temperature by 4°C to 7°C (Sattar 1987).

Drying Time

Timber of different species were dried in the experimental solar kiln in different charges throughout the year. Drying times for 2.5 cm planks from a green condition to a 12% moisture content level are given in Table 1 (Sattar 1987). It is evident from this table that the solar drying time is 54 - 72% less than the air drying time. Timber can be dried to the desired 12% moisture content during every season of the year whereas during the monsoon season 2.5 cm timber cannot be brought down to below 18% moisture content by air drying. Conventional kiln drying time is, however, 38-69% less than the solar drying time. Timber of other dimensions and species were also dried and similar findings were observed (Sattar 1987).

Table 1. Comparative drying times of 2.5 cm planks of different species for different drying methods.

Species	Drying Time (days) from Green Condition to 12% Moisture Content			% Reduction in Drying Time	
	Solar	Air	Kiln	Solar to Air	Kiln to Solar
(i) During winter period: November - March					
Chapalish (*Artocarpus chaplasha*)	10	22	6	55	40
Toon (*Toona ciliata*)	12	26	7	54	42
Teak (*Tectona grandis*)	13	28	8	54	38
Champa (*Michelia champaca*)	15	34	9	56	40
Koroi (*Albizia procera*)	17	38	10	55	41
Chickrassi (*Chuckrassia velutina*)	17	40	10	58	41
Jarul (*Lagerstroemia speciosa*)	18	45	10	61	44
Garjan (*Dipterocarpus spp.*)	18	48	10	61	44
Jam (*Syzygium grande*)	21	50	12	58	43
Gamar (*Gmelina arborea*)	26	68	14	62	46
(ii) During post-winter period: April - May; post-monsoon period: Septermber - October					
Chapalish	12	34		65	50
Toon	14	37		61	51
Teak	15	37		58	49
Champa	18	45		60	50
Koroi	20	49		60	51
Chickrassi	20	52		61	50
Jarul	23	63		63	57
Garjan	24	66		64	58
Jam	27	69		62	55
Gamar	31	82		62	55
(iii) During monsoon period: June - August (up to 18 - 20% moisture content)					
Chapalish	18	58		69	67
Toon	20	62		68	65
Teak	21	74		71	62
Champa	27	85		68	67
Koroi	28	93		70	64
Chickrassi	29	90		68	66
Jarul	32	106		70	69
Garjan	31	110		72	68
Jam	34	114		70	65
Gamar	40	123		67	65

Quality of the Seasoned Timber

The quality of the solar dried timber was found to be superior to both air and kiln dried timber. No objectionable defects were noticed in any batch of solar dried timber. Drying defects like end splits, surface checks and distortion were observed in severe form in many kiln and air dried timber specimens (Sattar 1982b, 1987). Better quality dried timber in solar kilns was also reported by many researchers (Plumptre 1979, Sharma et al. 1972, Troxell 1977).

ECONOMICS

Installation Costs

Cost is the main constraint in installing a conventional kiln suitable for small to medium scale wood-using industries in Bangladesh. The problem becomes more acute when the kiln along with the boiler needs to be imported. The erection cost for a 3.5 m^3 capacity solar kiln is estimated at Tk 28,000, the breakdown of which is furnished in Table 2. Against this, the cost of the conventional kiln of identical capacity is more than 35 times higher (Table 3). It is of particular importance to mention that no materials for the solar kiln need to be imported; all components can be procured from the local market.

Table 2. List of materials and their estimated cost for constructing a 3.5 m^3 capacity solar kiln in Bangladesh.

Sl. No	Materials	Quantity	Cost (Tk*)
1.	Sawn timber for super-structure and plywood for partition and northern wall	25 cft timber 4 Nos. plywood	8500
2.	Glass sheet for roof 5 mm x 2 ft x 3 ft	96 sq-ft	2400
3.	Glass sheet for three walls 3 mm x 2 ft x 2 ft	180 sq-ft	2700
4.	GI sheet for heat absorber, 10 ft long	3 Nos	600
5.	Blower fan, Aluminium, 24" dia with all accessories	1 set	4000
6.	Electric motor for fan, 1 hp, 600-700 rpm	1 No.	4500
7.	Enamel paint Matt black for GI sheet and other for wooden frames	2 Cans	700
8.	Concrete floor	13 ft x 9 ft x 1/2 ft	2400
9.	Carpenter and helper for making wooden structure	6 + 6 Nos.	1200
10.	Iron sheet for northern wall and nail, screw, bolt, etc.		1000
	Total:		28000

*Tk (Bangladeshi Taka) 32 ≈ US$1

Table 3. Comparative seasoning costs for 2.5 cm planks using solar and steam kilns.

Item	Solar Kiln of 3.5 m^3	Steam Kiln of 14 m^3
1. Output of seasoned timber per annum (based on 300 working days)	52.5 m^3 (15 charges)	420 m^3 (30 charges)
2. Recurring expenditure per annum** (Tk*)		
a. Fuel	Nil	215,000 (100 tons coal)
b. Electricity	3,133 (746W for 10 hrs/day)	13,440 (2kW for 16 hrs/day)
c. Loading and unloading	3,000 (4 man-day/charge)	12,000 (8 man-day/charge)
d. Operation/supervision	2,250 (3 man-day/charge)	60,000 (1 operator, 1 boilerman and 1 attendant)
e. Water	Nil	10,000
f. Maintenance	200	2,000
Total	**8,583**	**312,440**
3. Capital investment (Tk*)		
a. Initial installation	28,000 (solar kiln)	1,000,000 (equipment, boiler, building)
b. Working capital (1/4 of the total recurring expenditure)	2,146	78,110
Total	**30,146**	**1,078,110**
4. Economics aspects		
a. Recurring expenditure per annum (Tk*)	8,583	312,440
b. Interest on the total capital investment	4,522	161,717
c. Depreciation on initial investment (@ 10% for the solar kiln and 5% for the steam kiln)	2,800	50,000
Total	**15,905**	**524,157**
5. Seasoning cost/m^3 of timber	$\frac{\text{Tk } 15905}{52.5 \text{ m}^3} = \text{Tk } 303$	$\frac{\text{Tk } 524157}{420 \text{ m}^3} = \text{Tk } 1248$
6. Return on investment (assuming solar seasoning rate of Tk 1200/m^3)	$\frac{\text{Profit}}{\text{Investment}} \times 100$ $= \frac{\text{Tk } (1200\text{-}303) \times 52.5 \text{ m}^3}{\text{Tk } 30146} \times 100$ $= 156\%$	
7. Pay back period is about 7 months.		

* Tk 32 ≈ US$1

**Interest on value of timber in stock and land rent have not been considered.

Operating Cost

The operating cost of a solar kiln is low compared with that of a conventional kiln. No constant attendance of skilled operators is needed in solar drying, whereas it is indispensable for operating a conventional drying kiln. A huge expenditure is required for the supply of steam to the conventional kiln. It is estimated that more than Tk 200,000 are required for the supply of steam alone (Table 3). Contrary to this, the solar kiln receives free solar radiation for the heat energy. The operating cost is thus limited to casual attendance of an operator, electric power consumption of about eight units per day and loading-unloading charges of timber (Table 3).

It is estimated that the solar kiln seasoning cost of timber is Tk 303/m^3 against that of the steam-heated kiln drying of Tk 1248/m^3. It is further estimated that the return on investment is as high as 156%. This indicates that the total capital investment for the solar kiln will be paid back in about 7 months only (Table 3).

CONCLUSION

The BFRI solar kiln has been found to be efficient and economically advantageous for seasoning timber in Bangladesh. The solar kiln can conveniently be constructed using all local materials and facilities. Timbers of different species and dimensions can be dried to the desired lower level of moisture content throughout the year. Compared to conventional steam kilns the solar kiln is observed to be significantly cheaper in respect of installation and operation. This type of solar kiln, therefore, offers an appropriate technology for a country like Bangladesh for seasoning timber.

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