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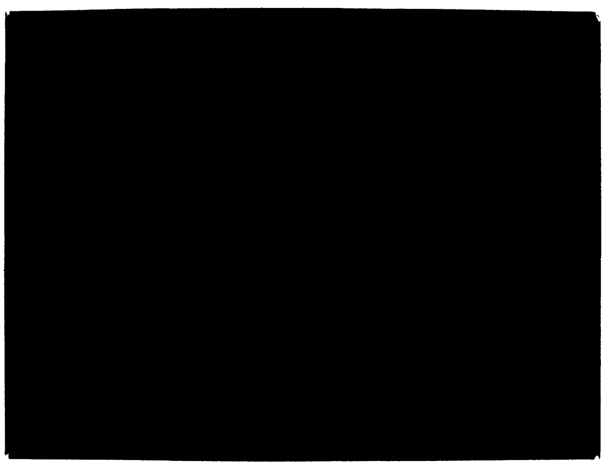
A VERSATILE, LOW-COST
DRYING KILN
FOR OPENING PINE CONES

by

A.M.J. ROBBINS*

1985

DEPARTMENT OF FORESTRY
COMMONWEALTH FORESTRY INSTITUTE
UNIVERSITY OF OXFORD



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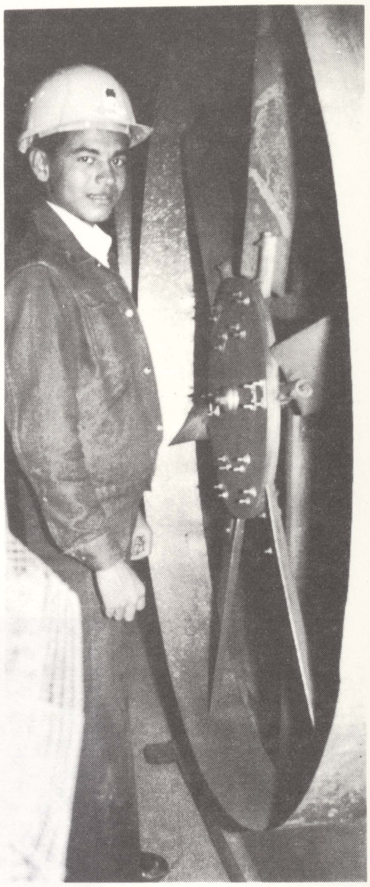
exterior



fan
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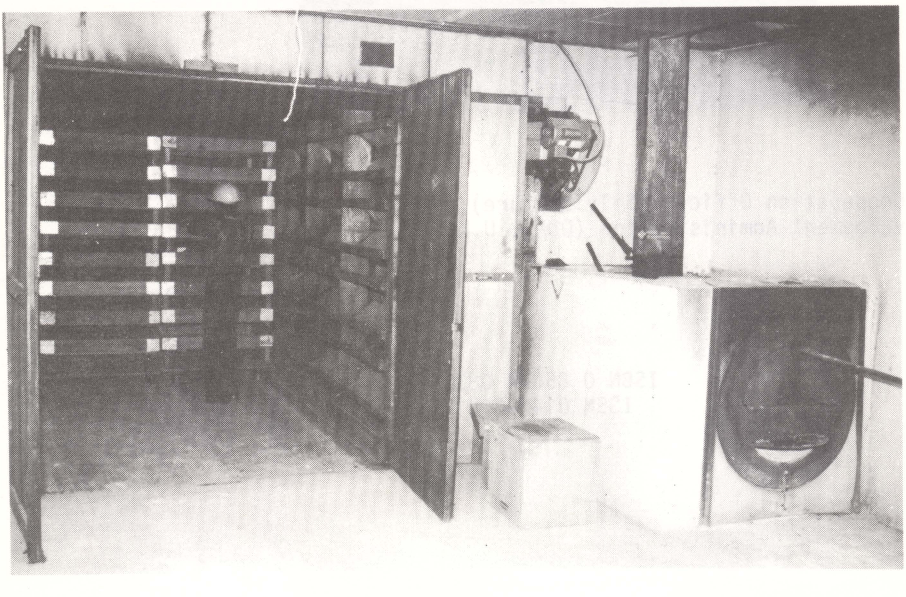
THE ESNACIFOR CONE KILN

drying chamber

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SUMMARY

A batch type, forced draught kiln is described, used principally for drying cones of Pinus caribaea and P. oocarpa in the Republic of Honduras, C.A.. Ventilation is by means of two, large diameter fans powered by an electric motor, gasoline or diesel engine. Air may be passed once through the kiln, or recirculated. Heating is by means of a furnace and flue radiator, using waste cones or firewood as fuel. Temperature is controlled manually with a precision of +/- 1°C. Cones or other products to be dried are placed in stacked trays, which can also be used for sundrying or precuring. Total capacity of the kiln is 3200 litres of closed cones. The design is simple, and all parts (including fans and heating system) can be made from material normally available locally in developing countries. The design should be suitable for countries that are initiating pine seed collection programmes. It is suitable for other forestry species, and should have application for drying agricultural products as well. Detailed plans are included, with notes on operation and construction.

PREFACE

During the period from November 1975 to January 1983, the Overseas Development Administration (O.D.A.) of the United Kingdom provided technical assistance to the Corporación Hondureña de Desarrollo Forestal (COHDEFOR) of the Government of Honduras for the establishment of a forest seed centre (Banco de Semillas) based at the Escuela Nacional de Ciencias Forestales (ESNACIFOR) in Siguatepeque. The kiln described in this paper was developed at the seed centre as part of this ODA project.

ACKNOWLEDGEMENTS

I am grateful for the assistance provided by the following organisations during the development of the kiln described in this paper:

Corporación Hondureña de Desarrollo Forestal (COHDEFOR)

Escuela Nacional de Ciencias Forestales (ESNACIFOR)

Instalaciones Eléctricas y Mecánicas, S. de R.L. (INEM)

Tropical Development and Research Institute (T.D.R.I.) (formerly Tropical Products Institute (T.P.I.)).

Commonwealth Forestry Insititute (C.F.I.)

Overseas Development Administration (O.D.A.)

In particular, I would like to thank the following persons:

Mr. Gwidon M. Buszewicz, (O.D.A.) for his background studies, research, development and training in seed processing during the project which laid the foundation for this study.

Sr. Oscar Ochoa Mendoza (Director, seed centre, ESNACIFOR), for his essential administrative and moral support.

Sr. J. Gonzalez (INEM), for technical advice in the actual construction of the prototype kiln.

The many Honduran labourers and artisans, for their work in the construction and running of the kiln.

Mr. C.E. Hughes, for assistance in testing the prototype.

Mr. R.H. Plumptre (C.F.I.), Dr. A.G. Gordon (U.K. Forestry Commission/E.F.G.) and Dr. L. Kennedy (T.D.R.I.), for their helpful first hand appraisal and criticisms of the kiln and suggestions for improvement. Messrs. Plumptre and Kennedy kindly reviewed the text of this paper.

Dr. J. Burley, for making available the C.F.I. Occasional paper series for publication of the results.

Miss E.C. Sowton for preparing the text for publication.

My wife, Gillian, for her unfailing support and encouragement, even during the many times I returned from work reeking of smoke and covered in soot.

A.M.J. Robbins
Oxford, July 1983

CONTENTS

TECHNICAL NOTE

(i) Moisture content percent is expressed on a fresh (wet) weight basis throughout this paper, in agreement with standard ISTA practice for seeds.

(ii) Approximate relations between weight and volume of pine cones:

Pinus oocarpa

Bulk density of closed cones (20% m.c.) = 35 Kg/100 litres
" " open " (12% m.c.) = 23 Kg/100 litres
100 litres of closed cones expand to 150-200 litres of open cones.
600 closed cones = 100 litres

Pinus caribaea

Bulk density of closed cones (40% m.c.) = 40 kg/100 litres
" " open " (12% m.c.) = 10 kg/100 litres
100 litres of closed cones expand to 200-300 litres of open cones.
800 closed cones = 100 litres

(iii) Any queries about the design and construction of the kiln, and requests for larger scale drawings should be addressed to the author:

c/o Unit of Tropical Silviculture
Commonwealth Forestry Institute
South Parks Road
Oxford OX1 3RB
U.K.

1. BACKGROUND

Seed collection of Pinus caribaea Morelet and P. oocarpa Schiede in Honduras is the responsability of the Banco de Semillas (seed centre) of the Escuela Nacional de Ciencias Forestales (ESNACIFOR), a department of the Corporación Hondureña de Desarrollo Forestal (COHDEFOR). The seed centre was established in 1975 with technical assistance from the Overseas Development Administration (ODA), U.K.

Annual collections of each species are around 1000 Kg. of pure seed and where possible cone drying for seed extraction is done in the sun. However, experience has indicated that it would be necessary to supplement the method with some form of kiln drying so as to avoid prolonged storage of cones during inclement weather, and also to increase seed yield.

Since drying is either done centrally, or near to collection sites for the remote provenances, two types of kiln were considered - a central, large, permanent kiln, and a simpler, smaller kiln suitable for field use.

Studies were started in Siguatepeque to see if enhancement of sundrying using a solar kiln might be appropriate for field use. A simple greenhouse convection kiln (mk. 1) was constructed, followed by 2 models (mk. 2 and 3) (see appendix 8) based on the forced draught timber drying kiln developed by Plumptre (1979). It was concluded, however, that the most effective method of solar drying of pine cones was by direct exposure to the sun, augmented by a transparent cover to produce a simple greenhouse effect, as described by Seward (1980) on a large scale, and Bryndum (1975) on a small scale, but even this method was hampered by the lack of a cheap, resistant, transparent roofing material, and was thus limited.

A small heater using discarded cones as fuel was installed in the mk. 3 solar kiln as a supplementary heat source during overcast periods, and proved such an economical way of heating that it was decided to discard the solar heating method and build a further kiln (mk. 4) based on the general configuration of the Oxford solar kiln but using artificial heat only.

The search for a suitable central kiln unfortunately proved fruitless, commercial designs being either (i) incompatible with the existing precuring and sundrying methods used, or (ii) too complex and automated for backup services available in Honduras, or (iii) too expensive. It was therefore decided to develop the proposed mk. 4 kiln such that it would be suitable both for central and field use.

The prototype kiln was finished in Feb. 1981, and has been in operation since. The design was drawn up principally by the author, with assistance from the local constructors, Instalaciones Eléctricas y Mecánicas S. de R. L. (INEM). The National Institute of Agricultural Engineering (NIAE), Silsoe, UK has commented on some aspects of the kiln, and the kiln was examined at first hand by Dr. L. Kennedy of the Industrial Development Department of the Tropical Development and Research Institute, U.K. (formerly the Tropical Products Institute (T.P.I.)).

This article describes the design, operation and performance of the prototype kiln, and also gives recommendations for improving further models, based principally on those of T.D.R.I. (Kennedy 1982).

2. GENERAL DESCRIPTION OF THE KILN. (See figure 1)

The design and development of the prototype kiln was determined by several criteria, which were that the kiln should be:

(i) Simple to make from local materials.
(ii) Versatile, suitable for intermittent use drying several cone lots, as well as for continuous use, drying large lots.
(iii) Compatible with the existing sun drying system.
(iv) Heated using local fuel, preferably waste cones or firewood.
(v) Simple to operate and maintain.
(vi) Capable of operating without an electricity supply in remote areas.
(vii) Suitable for drying fruits of species other than pine.

The resultant kiln is similar in layout to a sidefan timber kiln, (being based on the Oxford solar kiln), of batch type, using stacked drying trays for holding the cones, which are identical to those used for precuring and sun drying in Honduras. The trays are moved in and out of the kiln on wheeled pallets. The capacity is 3200 litres of closed cones.

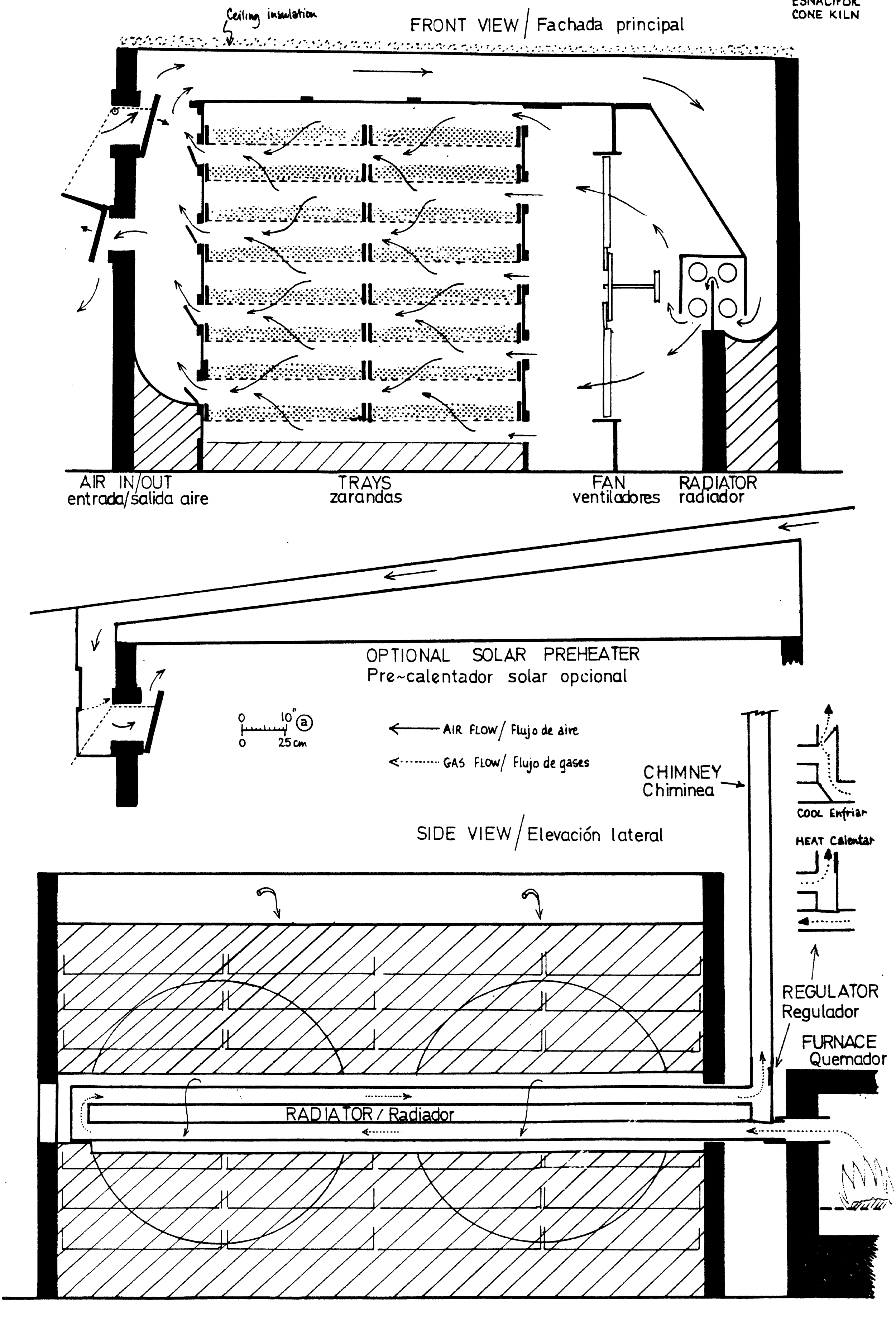
Air is circulated horizontally across and through the trays by means of two large diameter fans located at one side of the stack, powered by a 1 hp electric motor (or suitable diesel or gasoline engine), placed outside the kiln and connected via V-belts. Baffles either side of the tray stacks ensure flow of air through the trays.

Air enters and exits the kiln via two interconnected flaps in the side of one kiln wall. These may be adjusted so that either air passes only once through the kiln, or so that there is partial or complete recirculation of air.

Heat is provided by a small furnace, manually stoked with cones or firewood, placed outside the kiln, connected to a flue gas radiator which extends the length of the kiln behind the fans. The radiator is connected to a chimney by means of a regulator which enables the radiator to be bypassed and the furnace damped. Temperature control is obtained by observation of a thermograph, and manual operation of the regulator to suit.

GENERAL LAYOUT / Bosquejo general — Fig. 1 ③

ESNACIFOR CONE KILN



3. CONSTRUCTION AND DESIGN DETAILS

3.1 BUILDING (See figures 2-5)

3.1.1 Exterior:

The kiln can be built on an existing cement floor or patio, outside (as in the prototype), or under an existing suitable shed. Otherwise, separate foundations and a floor must be laid.

The main body of the kiln consists of three walls and parts of the fourth built of brick (as in the prototype). Cement or adobe blocks could be substituted, or, with suitable modifications to the design, cement/woodwool or other panelling could be used.

The main ceiling of the prototype consisted of wooden beams and two layers of asbestos sheet with a 4" air gap between. It is recommended that further kilns have a single layer of 8-12 mm plywood, topped with sawdust or other suitable insulation.

If the kiln is outside (as in the prototype), a roof will be required using either asbestos or corrugated galvanised iron sheet, extending over the front to provide a covered working and operating area. The roof could be constructed as a solar preheater, in which case a double layer of corrugated iron sheet would be used, the external surface being painted matt black (see figure 11 and Appendix 1). No roof is required if the kiln is constructed under an existing shed.

The fourth wall is completed by the access doors, made of tongue and grooved wooden boards (as in the prototype), or plywood panels. The intervening apertures are closed over using plywood.

3.1.2 Interior:

The interior of the kiln consists of a false ceiling and wall forming a duct for entry, recirculation, and flow of air over the radiator, made of plywood and galvanised sheet. The radiator is supported on a low brick wall running the length of the kiln in line with the burner.

Three partitions made from timber and plywood are fixed within the remaining area of the kiln. The nearest to the radiator supports the fans and electric motor (if used). The intermediate partition comprises baffles for the air entry side of the trays, and the third partition comprises baffles and flow adjustment louvres for the air exit side of the trays.

The partitions are constructed outside the kiln, then introduced and fixed to the main walls. The false ceiling, ducting, doors and panelling are then attached to the partitions.

The air intake/exhaust flaps are made from plywood panels, and hinged to the wooden frames that form the apertures built into the wall next to the exit partition. The flaps are counterbalanced and operated together by connecting one to the other with cord.

3.2 DRYING TRAYS (See figure 6a and 6b)

The drying trays are those used for precuring and sundrying by the Banco de Semillas. They are made of wood (89 cm. square, 10 cm. sides) with a double gauze bottom, the upper of 2 mm mesh (fly screening) to retain seed, and the lower of 6 mm mesh to support weight and give rigidity. Each tray has 4 feet and may be stacked on others up to 8 trays high. For mobility, each stack is placed upon a platform with 4 castor wheels.

The prototype kiln chamber accommodates 8 stacks of 8 trays each (64 trays total), sufficient for 3200 litres of closed cones (50 litres per tray, equivalent to 1-1½ cones thick). The space between trays allows for expansion as the cones open.

Alternate trays, twice the size (89 cm x 180 cm) can also be used, supported on platforms 180 cm. square. The kiln would accomodate 2 such platforms supporting 2 stacks of 8 trays each (32 trays total).

The trays are used for precuring outside the kiln stacked and under shade, and for sundrying they are placed individually on the drying patio.

3.3 VENTILATION SYSTEM (See figure 7, 8)

3.3.1 Ducting and Baffles:

The kiln is a batch type, and all cones dry at more or less the same rate. To ensure this, air is circulated across the stacks of trays, and baffles either side of the stack ensure that the air has to pass through the trays also before exiting. This is done by shutting off every alternate space between trays on the entry side, and reversing the closure on the exit side. The exit baffle apertures have adjustable louvres so that a certain control of airflow within the trays is possible, and allowance can be made for incomplete loads.

Once the air has passed through the trays, it is directed up and over the stacks via a duct formed from the false ceiling, returning down towards the radiator and fans via a continuation of the duct formed from a false wall made from galvanised iron sheet.

3.3.2 Air intake and exhaust:

Fresh air may be introduced and humid air exhausted by means of the two flaps on the wall next to the exit partition, interconnected by cords such that the entry flap opens inwards and the exhaust flap outwards. When the flaps are fully open, the entry flap blocks the way for recirculating air, which thus passes only once through the kiln. When the flaps are shut, there is complete recirculation of air. In intermediate positions, there is gradual exhaust of humid air, intake of fresh air, and partial recirculation.

The flaps are adusted manually from outside the kiln.

3.3.3. Fans and motor:

Air is circulated by means of two large diameter (1.5 m) propellor fans, rotating at 200 - 250 rpm. made from plywood and metal tubes, and mounted on their respective partition. The design of the fans was developed because of ease of construction, adjustment and balancing.

The central hub is made of plywood, to which are fixed the blades by means of short tubes and U-bolts. The first version of the fan (used in the mk. 2 and 3 kilns) had 4 blades made from pine planed to an aerofoil section. The prototype kiln uses a fan with 6 blades cut from slightly curved aluminium. Since the fans are low velocity and do not require aerodynamic sophistication, it is suggested that further fans have 8 blades made from flat plywood, as shown in figure 7.

The attachment of the blades allows easy adjustment of the angle of attack by rotating the stub tube and also of static balancing by moving the blade slightly in or out from the hub. Each fan has a short length of cowling to increase efficiency at the blade tips.

Power is provided by a 1 hp 1760 rpm electric motor, mounted on the outside end of the partition, and connected to the fans by pulleys and V-belts. An intermediate shaft and pulleys enable speed reduction down to 250 rpm.

In the absence of electricity, a generator could be used to supply the motor, or a diesel or gasoline engine used direct. In the latter case, the engine could be placed outside the rear wall, with an aperture made for entry of the V-belt, thus driving the inner fan first. This would enable more space to operate the engine, and noise and fumes would be away from the kiln operator.

If available, high speed direct drive fans and motors, such as used in the Oxford solar kiln, could be substituted. These have the advantage of requiring less power (each motor is $\frac{1}{4}$ hp), since no belts are used, and would be very suitable for a small generator.

The NIAE have commented that centrifugal fans would be more efficient and provide more uniform airflow (GORDON, pers. comm.[/1]). However, these are more difficult to construct, and would require modification of the design. Uniformity of airflow is discussed later.

3.3.4. Air flow data:

In the prototype, each fan was found to deliver 1.2 m^3/sec (no recirculation) up to 1.75 m^3/sec (complete recirculation) at 250 rpm. which appears to be reasonably efficient for the type of fan (Robbins 1981). The higher airflow with recirculation is due to the low pressure side of the fan being connected directly to the high pressure side, making flow more efficient. There is little difference in airflow with the kiln

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/1 DR. A.G. GORDON, referring to communication with DR. M.E. NELLIST, Crop drying and Ventilation Dept, National Institute of Agriculture Engineering (NIAE), Wrest Park, Silsoe, Bedford MK45 4HS. U.K.

full of cones or empty, indicating that there is low back pressure developed by the presence of cones. This is fortunate since propellor fans are not efficient working against a high pressure (Osborne 1977).

Assuming that the airflow through the cones is vertical, and that there is a 15% airspace between cones, the speed of air passing the cones is approx. 0.31 - 0.44m/sec. In the prototype, the speed of air passing the radiator is 2.5 m/sec.

Air flow uniformity through the trays was estimated. It appears that the periphery of the fans provides more airflow than near the hub, and there is even some back flow and a lot of turbulance as predicted by the NIAE. However, in practice the drying rate of the cones has been adequately uniform, from which it is deducted that the airflow must be uniform. This is probably due to the fact that the cones provide some backpressure, and that each tier of trays is open from one stack to the next, allowing the pressure to equalise across each tier. The provision of adjustable louvres in the exit partition has enabled further control of air flow, both horizontally and vertically, such that any observable variation in drying can be corrected, and account taken of incomplete loads.

The total volume of air circulating within the prototype is approx. 38 m^3 and this is completely recirculated every 15 secs. with the intake/exhaust flaps closed. Most of the tests with the prototype were done with partial recirculation, allowing a bleed out of air at a rate of 0.18 m^3/sec, such that an equivalent volume of air to the kiln volume is exhausted in approx. 3.5 min.

Further kilns can be made with closer spacing between the radiator, fans and entry partition, reducing the moveable air volume of the kiln to about 32 m^3, as shown in the plans.

3.4. HEATING SYSTEM (See figures 9, 10)

3.4.1. Furnace:

The prototype furnace consists of a rolled 6 mm. steel drum lined with firebricks, located within a brick enclosure filled with subsoil for insulation. The internal size of the furnace was similar to a 45 gal. drum from which it was developed. This worked well, but was unnecessarily complicated and expensive to make.

The recommended design for future furnaces is shown in figure 9, is rectangular in shape, made from ordinary bricks externally, and lined with firebricks. The top is made from a slab of reinforced concrete. The fire doors are from 6 mm sheet, side hinged, the upper for fuel loading, and the lower for air intake and ash removal. The doors must not overlap the front of the burner too much, as differential heating may cause buckling, as occurred in the prototype. Cast iron doors would solve this problem, but are difficult to make.

The grate in the prototype was made from cast iron, but could be welded from 35 mm iron reinforcing rods, but with a life of only 1 season. Surprisingly, the original grate, despite being cast iron, was severely deformed by the very localised high heat of the cone fuel. The recommended future design will spread the heat and reduce this problem.

The furnace size is such that cones can be shovelled in easily, and the depth is suitable for firewood lengths. It is possible that cones or even wood shavings could be introduced via a hopper set into the top of the furnace, thus facilitating stoking. With suitable modification of the grate, as described in Anon (1956), it might be possible to use sawdust as a fuel. The flue exit is a rectangular tube welded from 9 mm sheet.

3.4.2. Regulator:

The flue exit of the furnace is connected to the inlet of a regulator unit, welded from 6 mm sheet steel. The unit has two horizontal outlets for the flue radiator, and one vertical outlet for the chimney. A flap, controlled by a lever, enables the lower flue outlet to be shut off, so that gases are directed straight up the chimney, or opened, so that the gases exit via the lower outlet, pass through the radiator, and return to the chimney via the upper outlet.

A second flap in the chimney outlet, also controlled by a lever, allows the draught through the burner to be damped. A screw enables the closure of the damper flap to be adjusted. The levers are attached to the flaps such that they remain open or shut by gravity.

3.4.3. Flue radiator:

The radiator consists of a horizontal flue, made (as in the prototype) from two parallel lengths (3.7 m) of 24 gauge galvanised iron sheet rectangular tubes, spaced 25 cm between centres, attached at one end to the regulator, and at the other by a U-bend. A removeable panel in the U-bend enables cleaning of the flues in-situ, via an access hatch in the far kiln wall, through which the entire radiator can be removed. The ducting around the radiator ensures that the air to be heated flows fast and close to the tubes.

The surface area of the prototype radiator was 4.9 m^2, plus an additional 2.5 m^2 made up of corrugated cooling fins, jammed in place above, below and between the radiator.

The prototype radiator was very easy to make, but suffered from two disadvantages. As pointed out by Dr. Kennedy, with a duct of rectangular cross section, the heat transfer between flue gas and airflow over the tubes is inefficient (although adequate in the prototype). Also, the section of the lower tube next to the burner burnt through in one year. This latter problem has now been solved, substituting the first 65 cm. of the tube by one welded from 3 mm steel sheet.

It is suggested that further kilns should have radiators using round steel tubes if available, either constructed from four 100 mm diam. tubes arranged side by side, or from two 130 - 150 mm dia. tubes. The alternatives are shown in figure 10. It should be noted that round, galvanised iron sheet tubes are difficult to make due to the problem of rolling, whereas rectangular shapes are easy and for that reason can be used if no round steel tubes are available. The advantages of more efficient heat transfer if round tubes are used are given later.

The tubes are fixed rigidly to the regulator, but allowed to slide in and out of sleeve joints in the U bend so as to permit differential expansion of the tubes. These joints and access panel must be a good fit to avoid gases being sucked out. Although the chimney creates low pressure in the radiator, the fans create an even lower pressure around the radiator, such that gases will be sucked out. This has not been a problem on the prototype, where some leakage was experienced, but may be important if the kiln is used for drying material such as cocoa which could be tainted by the smoke.

3.4.4. Chimney:

The chimney is a duct made from galvanised iron sheet, and in the prototype is of similar dimensions to the radiator tubes. A removable panel in the lower end of the chimney would enable it to be cleaned in situ. Otherwise, cleaning is done from the roof, or by removing the chimney entirely.

A thermometer attached to the surface of the chimney at the base gives an idea of the chimney temperature.

3.4.5. Temperature control:

Temperature is maintained at the desired level by observation of a thermograph placed behind a transparent window in the fan access door. The graphs are premarked with two lines indicating the upper and lower limits of variation of the temperature required (usually +/- 1-2^{o}C). The operator observes the trace, and when it reaches the upper limit, adjusts the regulator to bypass the radiator and damp the burner, thus cooling the kiln. When the trace reaches the lower limit, the kiln is heated again by opening the regulator, allowing passage of flue gases through the radiator with full draught, and so on.

Further temperature control is effected by the rate of stoking, which is increased at the beginning of the drying period to get rapid heating of the kiln and contents, and reduced when all the contents are at operating temperature. The chimney thermometer, in conjunction with the thermograph, is useful for determining when the burner should be replenished.

The frequency of operation of the regulator to maintain the temperature within limits depends on the fuel type used and rate of stoking. Cones tend to burn and release heat rapidly, requiring operation of the regulator every 10-15 minutes (see appendix 2), whereas firewood burns more slowly, and the temperature changes are slower. With experience, the temperature can be maintained within limits by stoking only, leaving the regulator open.

This method of temperature control has worked very successfully. Even at limits of +/- 1^{o}C, little experience is required to maintain the trace within them, without undue fuss in operating the regulator. The trace is useful for indicating when the radiator should be cleaned or if there is some malfunction, since small changes in the rate of heating or cooling are readily apparent. It is also possible to tell at a glance if the temperature is rising or falling. Any deviation of the required temperature is permanently recorded on the trace, which is a useful and necessary check on the operator's control.

If, for any reason, the temperature increases too much in the kiln, it can be reduced very rapidly by opening the air intake and exhaust flaps of the kiln, introducing cool, fresh air.

3.4.6. Fuel types and consumption:

The main fuel used for the prototype has been discarded *P. oocarpa* cones. For a 40 - 45 °C kiln temperature (15 - 20°C above ambient), the rate of burning is about 10 litres of open cones (a large shovelfull) every 8 minutes reducing to 10 litres every 15 minutes when the kiln has heated up. Cones are ideally shaped for burning quickly, and are best stoked little and often.

Cones of *P. caribaea* have also been used, and since they have about half the bulk density of *P. oocarpa* cones, 20 litres of cones must be introduced for the same rate of stoking.

Care must be taken not to produce a lot of smoke (see later) which can be avoided by ensuring sufficient air intake to the furnace, keeping the burner reasonably hot, but not overstoking.

Pine firewood has been used, which is slower burning and required less frequent stoking. It is very possible that wood shavings could be used satisfactorily and also sawdust, provided the grate was modified. For more efficient combustion, a small air blower could be attached to the lower ash door of the furnace.

Fuel types that flow easily might best be introduced via a hopper set into the reinforced concrete roof of the burner, with a manually rotating paddle feed.

A summary of the fuel characteristics used is given in appendix 3.

3.4.7 Performance of heating system:

The flue gases that leave the furnace are estimated to rise to about 500°C or more, and once passed through the radiator reduce to 80-150°C, giving an average estimated surface temperature of the radiator between 150° - 200°C. The temperature rise for a single pass of air at that temperature is from 6 - 10°C. The maximum rise has been 20°C, with maximum stoking, when the first metre of radiator tube was red hot.

At normal rates of stoking, recirculation of the air is necessary to reach the required kiln temperature, using the existing prototype radiator. If the more efficient round tubular designs are used, improved heat transfer will be possible, thus enabling better fuel consumption, and/or less need for recirculation. This latter advantage is discussed later.

The heating system requires that chimney gases are sufficiently hot to provide sufficient draught. A very efficient radiator might extract so much heat from the flue gases so as to reduce convection flow. This does not seem to be a problem, since the gases that exit the radiator into the regulator are reheated somewhat by conduction through the walls of the regulator, and also by a certain bleed of gases past the radiator control flap. If required, the chimney could be insulated to maintain heat, but this has not been necessary on the prototype kiln.

Since the radiator doubles back on itself, the average temperature of the parallel tubes remains more or less uniform, and air leaving the radiator is heated evenly. Any uneveness disappears when the air is mixed by the swirling airflow produced after passing through the fans. There tends to be stratification of temperature within the tray chamber (due to convection) such that the upper trays may be 1^{o}-2^{o}C hotter than the lowest.

It appears that the large heat capacity of the kiln walls and contents is important in damping temperature changes within the kiln, which is an advantage in that temperature control is easy. The heat that is absorbed by the walls and in particular the furnace is in part stored and is reusable, such that considerable drying can be achieved at the end of a run, leaving the kiln unstoked, but with fans running, so as to use up this stored heat.

The prototype kiln is un-insulated, except for that provided by the bricks themselves. Heating efficiency could be increased by complete insulation, but this would have to be weighed against the increase of cost. To avoid difficult temperature control due to rapid fluctuations, it would probably be better to insulate the kiln on the outside, so that the damping effect of the walls could still be utilised.

An energy balance for the kiln is given in appendix 4. Efficiency appears to be acceptable, with an "overall drying efficiency" of 18%, as defined in McDonald et al (1981) (compare with similar designs used for cocoa given by McDonald). A more efficient radiator and insulation could increase the value significantly.

3.4.8. Maintenance:

The heating system has required little maintenance, but one important aspect must be observed. The radiator flues act as efficient distillation tubes for unburnt vapour, and build up of creosote and soot particles can be very rapid, particularly if the burner is kept understoked and running cool; overstoked so that combustion is incomplete; or if very smokey fuel is used.

Therefore every 50 hours of operation (sometimes less) the radiator flues have to be cleaned out. The design of the tubes and regulator makes this a very simple job, using suitable scrapers and brushes introduced through the radiator access hatch and panel in the U-bend. The deposits are finally pushed back into the burner. The chimney requires less frequent cleaning, either via an access panel in the front of the chimney, or from the roof, or by removing the chimney.

The flues must also be inspected every so often for signs of burning through. This is important to avoid accidental entry of sparks into the kiln, and resultant high risk of fire due to the inflammable nature of the cones being dried.

4. DRYING CHARACTERISTICS OF THE KILN

4.1 DRYING REGIMES

4.1.1. Relative humidity:

The initial relative humidity (RH) of the air within the kiln depends on the ambient RH and the increase of temperature given to the air, and can be calculated from psychometric tables; it cannot be controlled directly. Once drying commences, the RH of the kiln air will rise to a level determined by the wetness of the cones being dried, the rate of exhaustion of moist air from the kiln and intake of fresh.

Since recirculation is normally required to reach the desired temperature, a compromise has to be reached between temperature, RH, and fuel consumption of the kiln.

Little study has been possible to determine the best rate of exhaustion, but most drying appears to be satisfactory with a rate of $0.18m^3$/sec, which gives a kiln RH at the entry to the trays from 40% (40°C kiln temp., humid day), down to 20% or less (50°C kiln temp., cool, dry day).

If the kiln is used in tropical lowland climates with a high ambient RH and temperature, recirculation will have to be reduced to keep the kiln RH acceptably low to ensure good drying. This may require a higher fuel comsumption which would be offset somewhat using the more efficient radiator design.

In climates that have relatively cool nights, drying may be more efficient during the night, since the ambient air has to be heated more to arrive at a given kiln temperature, such that, dependent on the initial RH, the final kiln RH will tend to be less. This is certainly the case for temperate climates.

During the day, the use of the solar preheater mentioned in appendix 1 would reduce the need for recirculation, and thus enable a lower RH to be achieved.

Although no conclusive results have been obtained, it is possible that cycles of complete recirculation until the maximum drying capacity of the air has been used, following by complete exhaustion of the air and replacement by fresh, and so on, might be more energy efficient, and could promote better opening of cones.

The RH of the kiln can be measured by a hygrograph, placed behind a transparent window in the fan access door, in a similar way to the thermograph.

4.1.2. Temperature:

The maximum temperature that can be used for drying pine cones depends on the moisture content (m.c.) of the seed and cone. Seed that has a high m.c. is more susceptible to high temperature damage than seed with low m.c.. Normally, *P. oocarpa* can withstand temperatures of up to 50°C without loss of viability, whereas *P. caribaea* is best kept below 45°C.

Most drying runs for P. oocarpa have been at a constant 50°C although initial runs began with a period at 40°C. Since P. caribaea cones are much more moist when entering the kiln, constant temperatures of 40°C to 45°C have been used.

Temperatures up to 60°C can be achieved in the kiln, which is the maximum allowable for any seed. Even higher temperatures can be reached with recirculation, but would only be required if the kiln were used for drying dead matter. A probable maximum of 80-90°C is likely for the kiln, but has not been tried.

The method of temperature control by observing premarked limits on a thermograph enables virtually any temperature regime to be followed, provided that very rapid rises in temperature are not required, and subject to a minimum practical variation of +/- 1°C.

4.1.3. Time:

The time required to dry and open the cones depends on the initial m.c. of the cones, the species, and the temperature and RH prevailing in the kiln (see section on drying rates).

Normal periods for both P. oocarpa and P. caribaea are from 12 - 18 hours at constant temperature. The actual period used for the prototype kiln was dependent on the working day, it being difficult to employ an operator out of working hours. As such, it was found that a period of 8 hours operation at constant temperature could be followed by a further 6 hours of unattended operation, keeping the fans running, the air intake/exhaust flaps shut, and using the heat stored in the burner, walls and contents of the kiln. During this stored heat period, the kiln temperature would reduce to 5 - 10°C above ambient. The fans would be switched off overnight, and the load left in place so as to limit reabsorbtion of moisture. This regime was not always sufficient to dry a load, and further drying would be required the next day.

When personnel was available, the prototype was run for a week continually, using 8 hour shifts. This was much more efficient for several reasons. The amount of fuel used was reduced, since the heat-up period was omitted; sooting up of the radiator tubes was reduced; and production was increased, since at constant temperature up to two loads could be dried in the 24 hour period. Wherever possible, continuous running is recommended, stopping when necessary to carry out maintenance.

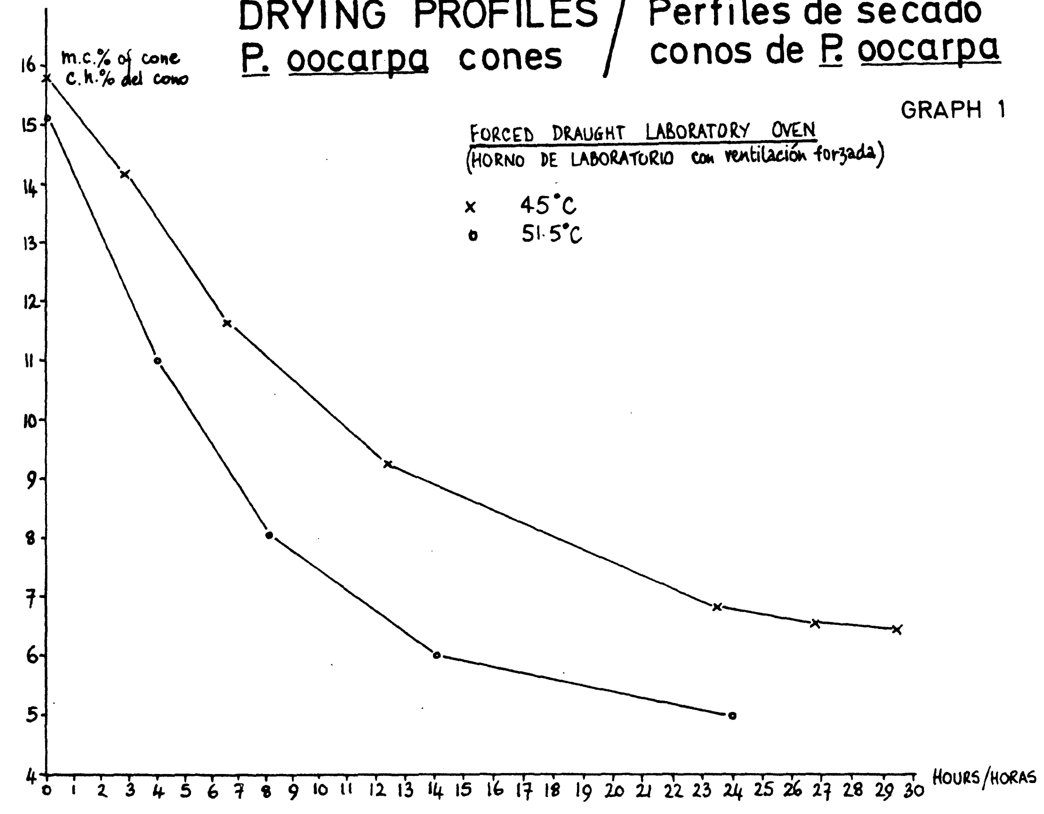
4.2. DRYING RATES

Pinus oocarpa cones are normally collected during the dry season (Jan.-Mar.), when the cone is brown and dry, with a m.c. (fresh wt. basis) of 20 - 25%. The cone is woody, and has quite thick scales, and can be placed directly in the kiln without need for precuring, but normally the cones will receive a period of predrying of about 1 - 2 weeks, when the m.c. will have reduced to about 15%. Ambient drying conditions are generally good, and a low RH can be obtained in the kiln, giving a drying rate from 0.3 - 0.5 percentage points/hour. (See graphs 1 & 2)

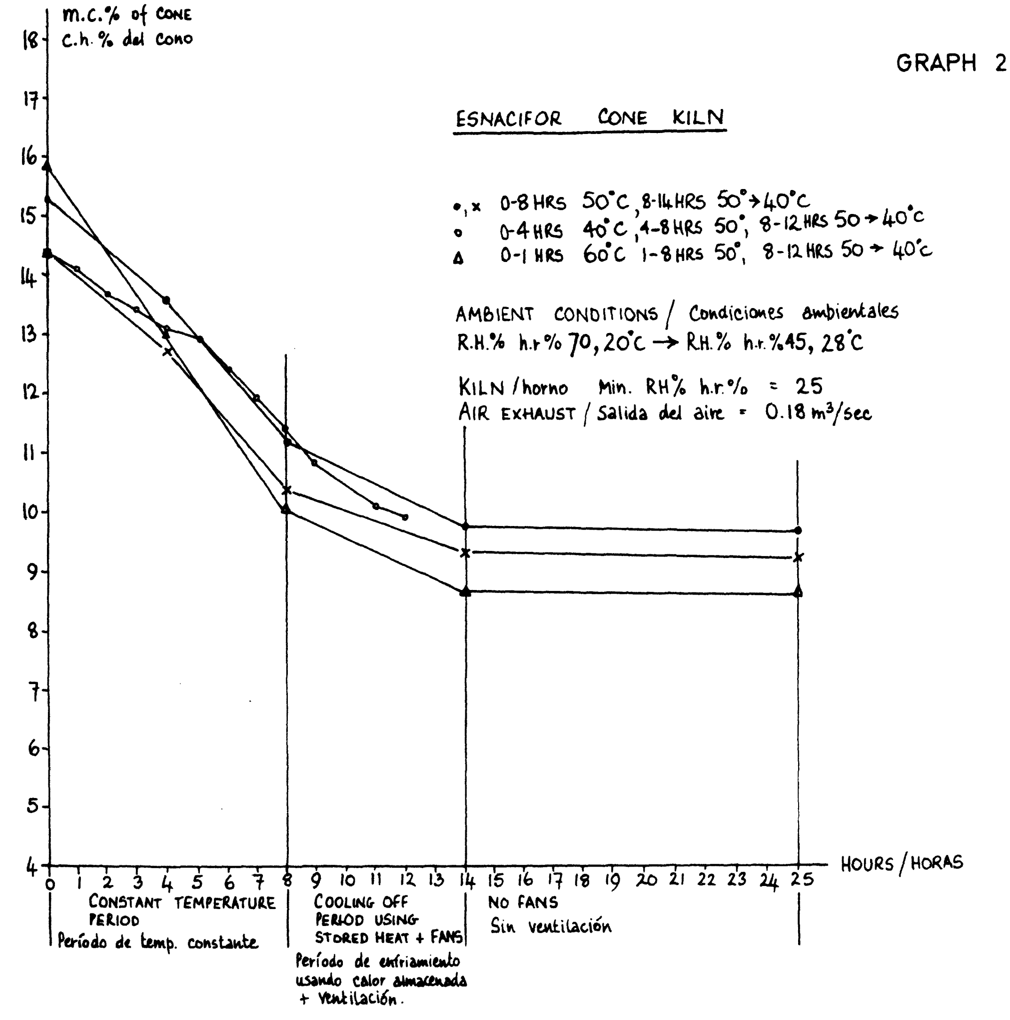
Pinus caribaea cones are normally collected during the wet season (May -

DRYING PROFILES / Perfíles de secado
P. oocarpa cones / conos de P. oocarpa

GRAPH 1

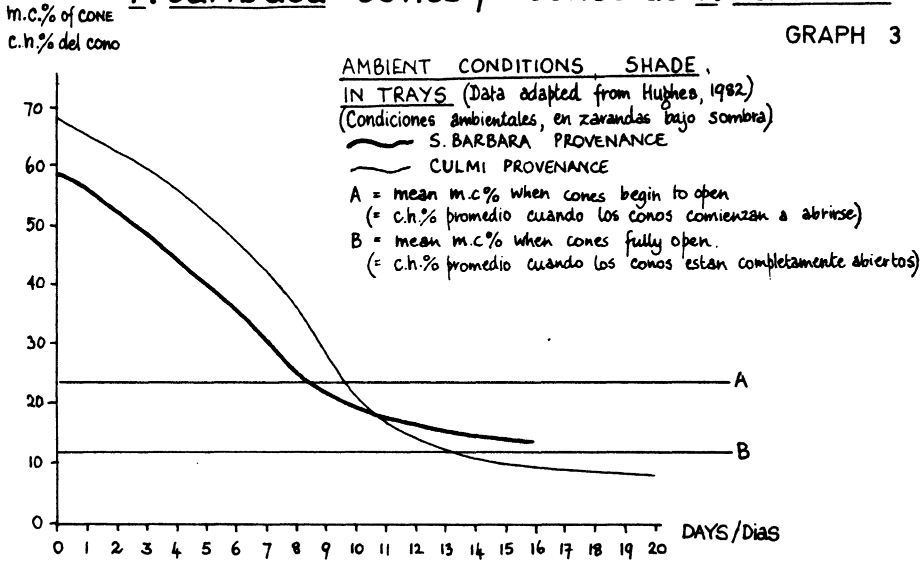


GRAPH 2

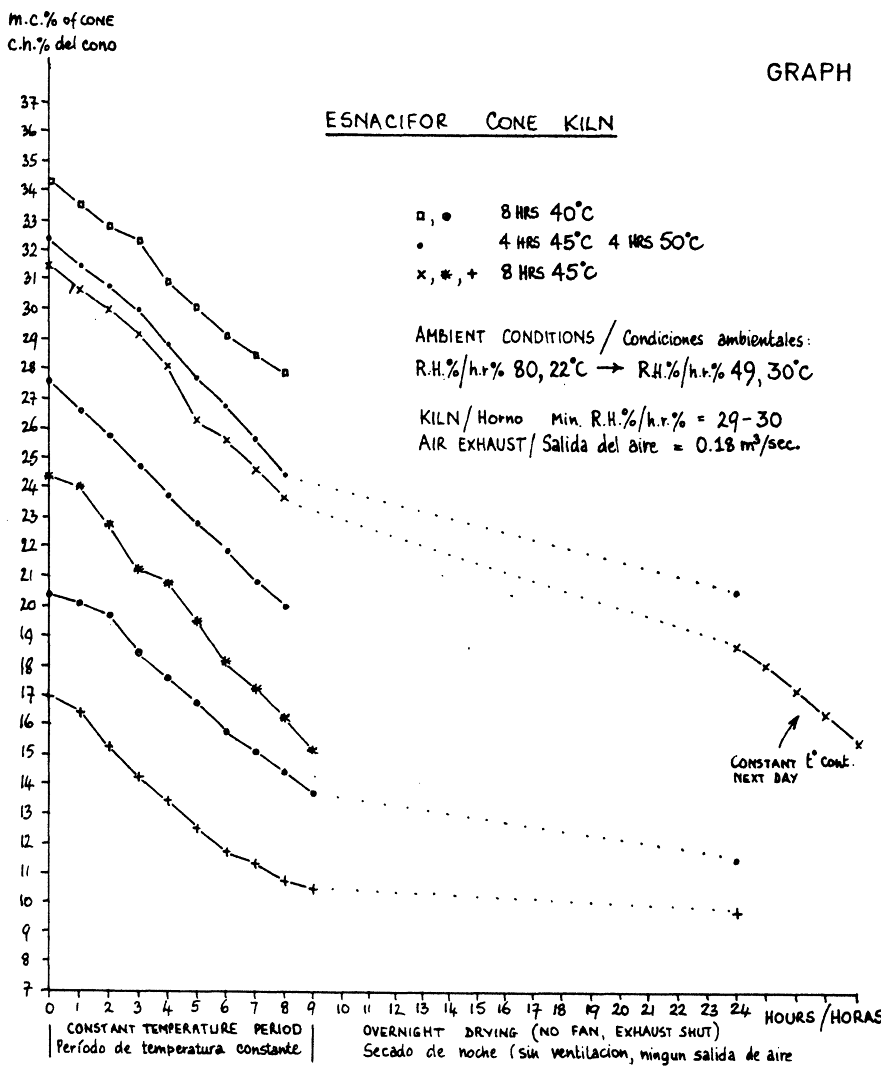


DRYING PROFILES / Perfíles de secado
P. caribaea cones / conos de P. caribaea

GRAPH 3



GRAPH 4



July), when the cone is half green and moist, with a m.c. of 40 - 60%. As such, the cones must receive a period of precuring in the drying trays under shade for 10 - 20 days, after which the cone m.c. will have reduced to about 20 -25%. Ambient drying conditions are often very poor, since it is frequently raining. However, kiln drying rates are faster than with P. oocarpa, due to less woody and thinner cone scales. Normally, the m.c. is reduced by 0.78 - 1.5 percentage points/hour over the range of 10 - 20% cone m.c. (see graphs 3 & 4).

Prosopis juliflora pods have been dried (partial charge of 28 trays). These entered with a m.c. of 25% and reduced to 7.5% after 5 hours, giving a drop of 3.5 percentage points/hour (temp. 50°C).

Coffee beans have been dried, spread in layers of 12 - 25 mm deep within the trays. Final m.c. was approx. 9%, but initial figures were not calculated. According to the coffee owner, drying rate was good.

4.2.1. Air circulation:

During observations of the drying rates, it was noted that adequate air circulation was essential to proper drying. On occasions, the inner fan belt would slip, so that there was reduced air circulation through the inner trays. This caused significantly reduced drying, judging from cone opening. It was also noted that when the fans were switched off after the period of operation using stored heat, the drying rate would reduce greatly, in some cases to nil, although the kiln was still warm (see graphs 1 - 4). However, the airflow rate normally produced by the fans is considered adequate, and may even be too high for maximum electrical economy.

4.3. DRYING RELATED TO OPENING OF CONES.

Pinus oocarpa: The object of drying cones is to open them and release the seeds. If P. oocarpa cones dry too slowly, the cone may not open properly, and this can be a problem if the cones are stored for too long in sacks. This can be solved by soaking the cones in water for 24 hrs.to increase the m.c. before drying in the kiln. The cyclic drying regime mentioned earlier may be useful in promoting better opening, since natural conditions are copied. It appears that kiln drying helps to increase seed yield by up to an estimated 10%.

Pinus caribaea cone opening has been studied in more detail (Hughes 1981). On average, the cones begin to open at around 24% m.c. and are fully open at 11% m.c.. It appears that the rate of drying or changes in temperature etc. do not change this relationship. Although the drying rate was faster with this species, greater difficulty was experienced in obtaining uniform opening of loads. This appears to be due to the great variation in cone m.c. of each lot, which in turn is due to the variation in maturity of the cones within and between trees in stands, and between stands. Cones that are collected immature will open at a lower m.c. or not at all.

Appendix 6 gives a list of features that are taken into account when assessing efficiency of opening.

4.4. Production of seed

Pinus oocarpa: The yield of seed from P. oocarpa cones varies from 160 - 250 g/100 litres of closed cones, depending on provenance and cone selection. Thus for each complete kiln load of 3200 litres of cones, a yield of 5 - 8 Kg. of pure seed should be possible. If the kiln were used 24 hours a day, it should be possible to dry 1.5 - 2 loads per day, equivalent to a maximum production rate of 7.5 - 16 Kg. of pure seed/day.

Pinus caribaea cones yield 125 - 625 g of pure seed/100 litres of closed cones. The wide variation is due to variation between provenances (the yield from P. caribaea var. hondurensis coastal sources is the poorest), annual variation in pollination, selection of cones, and cone maturity. As with P. oocarpa, 1.5 - 2 loads can be dried every 24 hours, depending on the amount of precuring given to the cones, equivalent to a maximum seed production of 6 - 40 Kg/day.

5. CONCLUSIONS

The 2 years of operation of the prototype kiln have generally been successful, and have confirmed that the design fulfills the criteria mentioned in the introduction.

It is felt that the design, embodying the modifications suggested in the text (mostly recommended in Kennedy 1982) would be suitable for seed programmes in other countries, particularly where P. oocarpa and P. caribaea are being collected. It may also be suitable for certain agricultural products, such as coffee, cocoa, beans, spices etc. which do not provide high resistance to air flow. It is probable that even products that do have high resistance can be dried successfully, ensuring that each tray is only lightly loaded.

A summary of the kiln's advantages are as follows:

1. It is versatile. The use of standard sun drying/precuring trays, which in themselves are versatile, is very convenient and reduces handling. The smaller size tray is appropriate for one man handling, suitable for individual tree collections and for fruits other than pine. Since drying is done in batches, it is easy to apply an appropriate drying regime for each species and state of maturity, and there is no problem with intermittent use.

2. It is simple to construct. The kiln was constructed entirely from local materials. The level of expertise required to make the fans and heating system is no more than that of a skilled worker in carpentry or welding. The electric motor or engine are standard imports to most countries. The thermograph may have to be imported, but is standard laboratory equipment.

3. It is simple to operate and maintain. Experience has shown that the operator requires very little training to economise on fuel and obtain a temperature within +/- $1^{o}C$. The only important maintenance comprises cleaning and checking the flues, checking the fan drive and pulleys and belts, and also the accuracy and

operation of the thermograph. The kiln could be installed and operated in most remote areas. Only one full time operator is needed to run and load the kiln.

4. It is economical to install and run. The present kiln should cost no more than U.S. $6,000.00 to build with local material and labour and running costs are low (see appendix 7).

The layout of the kiln should enable it to be sized according to requirements. A smaller version would best be made reducing the width to only one tray, instead of two. A bigger version could be attempted increasing the length to include an extra fan, increasing the capacity by 50%. In this case, the burner might need to be fractionally larger, and the tubular steel radiator tubes should be used.

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APPENDIX 1

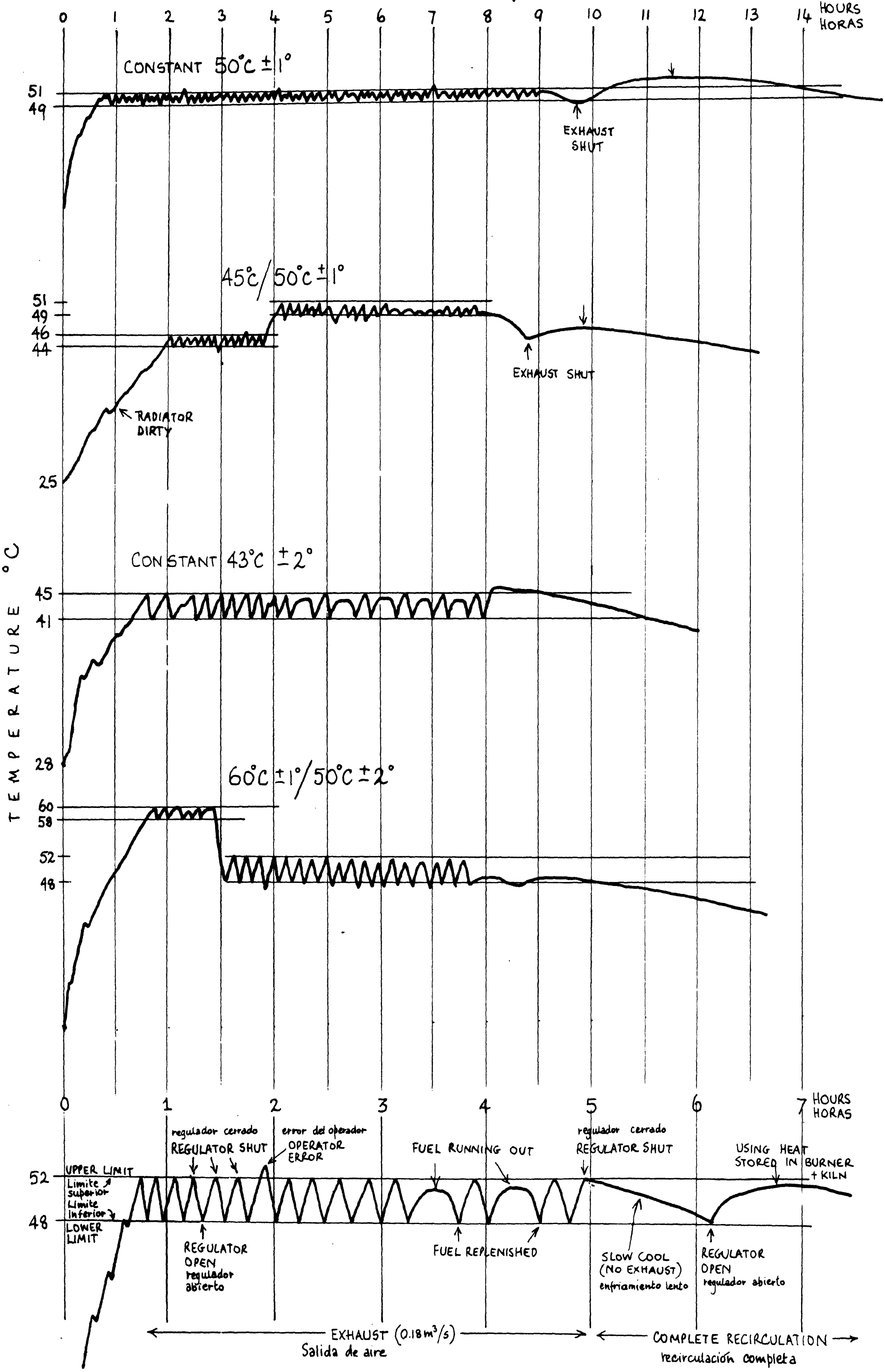
Details of Solar Preheater

If the kiln is constructed with its own roof, this can be arranged to act as a solar preheater for air drawn into the kiln. The layout is shown in figure 11.

According to TPI (Kennedy, pers. comm.), for a 4 x 4 m roof, at an insolation rate of 700 W/m^2, and an air flow rate of 0.2 m^3/sec., a temperature increase of approximately 8^oC should be attained. This is an energy input of 2 KW (=1720 kcal/hr). The temperature gain is a conservative estimate, and may well be higher. When the roof is wet, it is better if the air does not pass under the roof as this may result in cooling of the ambient air. By using a hinged flap (see figure 11), air can be taken either direct from the ambient air, or it can be passed under the blackened roof.

Assuming that the above input could be maintained for 6 hours on a sunny day, a total of 10,320 kcal could be saved in heating incoming air. (In the above example, the intake of air is 0.2 m^3/sec, compared with 0.12 m^3/sec currently used for the kiln).

THERMOGRAPH TRACES / Trazas del termógrafo



Appendix 3

Detail of fuel types used

	Open cones		Pine Firewood
	P. oocarpa	*P. caribaea*	
Bulk density (g/litre)	233	104	710(**)
Higher calorific value (kcal/g)	4.88	4.5(*)	4.9
Fuel consumption (heatup period)	115	200	48
(litres/hour 20°C ambient Temp.) (constant 40°C)	40	80	16
(constant 45°C)	50	100	20
(constant 50°C)	60	120	24

Notes: Wastecones provide more than enough fuel to run the kiln. For example: A full load of closed *P. oocarpa* cones is 3200 litres. These will open to produce 4800 litres of open cones. At 50°C, fuel consumption is 60 litres/hour after initial warming up. Thus the kiln could be run for 80 hours on the waste cones from one load. A normal drying period is 12 - 16 hours, thus a maximum of 20% of the waste cones will be used.

(*) Estimated

(**) Wood density (not bulk)

Appendix 4

Energy balance of kiln

The following summary is based on a typical run, drying *P. caribaea* for 10 hours at 45°C, when approx. 500 litres of open *P. oocarpa* cones were used as fuel. Detailed calculations are given in Robbins (1982), modified to take into account a revised estimate of the calorific value of the fuel.

Summary of energy balance (kcals)

	+	-		% of total	
Effective heating value of fuel (*)	366,000				
Energy required for evaporation (**)			66,960		18.3%
Energy required to heat kiln and contents:					
Building		44,605		12.2%	
Cones		18,200		5.0%	
Wood structure		13,500		3.7%	
Metal structure		2,500		0.7%	
Air exhausted		27,820		7.6%	
Subtotal			106,625		29.2%
Energy lost through conduction:					
Walls of kiln		27,869		7.6%	
Floor of kiln		28,695		7.8%	
Doors		14,028		3.8%	
Ceiling		14,000		3.8%	
Subtotal			84,592		23.0%
Other losses (radiant heat from burner, chimney gases, and others unaccounted for)			107,823		29.5%
	366,000		366,000		100.0%

Notes: (*) The effective heating value (=3.66 kcal/g) was calculated from the higher heating value (measured in a bomb calorimeter) of 4.88 kcal/g, deducting 25% due to losses from moisture heat, hydrogen heat, dry gas and excess air, as described in Ince (1977).

(**) This value expressed as percent is equivalent to the Overall Thermal Efficiency, defined in McDonald *et al* (1981)

Ambient temperature was assumed at 20°C.

No account is taken of the energy required to drive the fans.

Appendix 5

Measurement of kiln performance

During the first year of operation, detailed studies were carried out on the kiln in an attempt to evaluate its performance. The following notes give the methods used.

Airflow: The total volume of air moved by the fans and the relative air speeds in different parts of the kiln were measured using a SEI Velometer. Total airflow was measured with the Velometer placed in the upper recirculation duct, and a mean obtained from readings at different heights in the duct. Calculation of airspeed in other parts of the duct and kiln was based on relative cross sectional areas.

Uniformity of airflow was estimated firstly by readings of the Velometer within the tray chamber, without trays. As mentioned, this was found to be variable and turbulent, but did not represent the actual flow when the kiln was loaded. Since it was impractical to use the Velometer between full trays, air flow uniformity was estimated assuming that it would be proportional to drying uniformity, which in turn would be proportional to cone opening which could be easily observed.

Temperature: Temperature in various parts of the kiln was measured using thermometer (ordinary, and maximum and minimum), and thermographs. On the basis of these studies, it was found that the position of the thermograph used for temperature control was representative of the kiln as a whole, tending to read a fraction higher.

Relative Humidity: This was measured using a sling hygrometer for ambient conditions, and with a hygrograph within the kiln, placed underneath the thermograph, measuring condition of the air entering the trays. The studies of this factor were limited due to lack of time.

Moisture content of cones: The m.c.% was calculated on a fresh weight basis, drying to constant weight at 105°C in a laboratory oven. Normally, the progress of drying was based on a permanent sample of 25 cones, placed in a gauze container on the 4th. tray from the top of the stack nearest to the exit partition and main door. This position appeared to be representative of the kiln as a whole and was easily accessible. No replications were used.

Data gathered during drying: During the first year of kiln operation, detailed measurements were taken during each run, which comprised the following:

(i) Kiln thermograph trace (always available)
(ii) Kiln hygrograph trace
(iii) Record form, giving: (a)date, (b) run i/d no., (c) operator (d) species and provenance, (e) predrying time, (f) quantity of cones (g) measurements every hour of: quantity of fuel, ambient temp. (wet and dry bulb), ambient RH%, mc% of cones, and proportion of cones shut, half open, and open (using the permanent sample of 25 cones), (h) weight of seed extracted and physical quality for some runs), and (g) observations and details of adjustment of kiln etc.

An example kiln record form is given below , with typical run data for P. caribaea. A total of 23 runs were completed in the first year, during which detailed measurements were taken. In the second year, 54 runs have been completed at the time of writing. In these runs, which are considered as routine, rather than experimental, the data has comprised the thermograph trace on which details of kiln adjustments and seed lot i/d are recorded only.

Example of control form and graphs of kiln run with P. caribaea

CHARGE NO: 19 DATE: 2/7/81 OPERATOR: Rómulo

SPECIES: P. caribaea PROVENANCE: Santa. Barbara.

PREDRYING TIME: 2 weeks

CONE VOLUME: 3,200

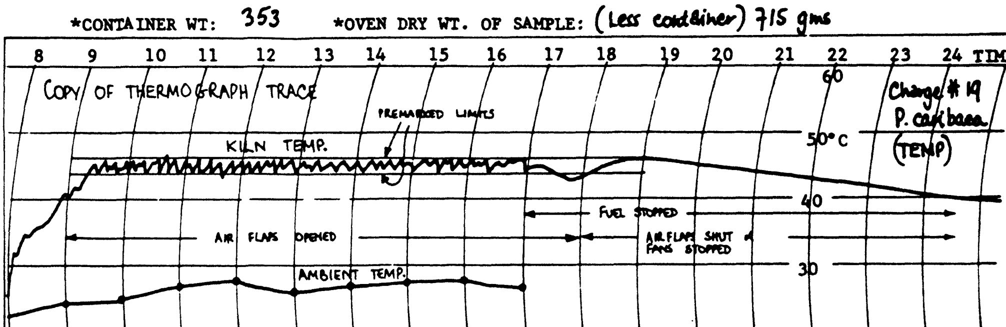
DRYING REGIME (see thermo/hygrograph trace): 8 Hrs @ 45°C + overnight drying

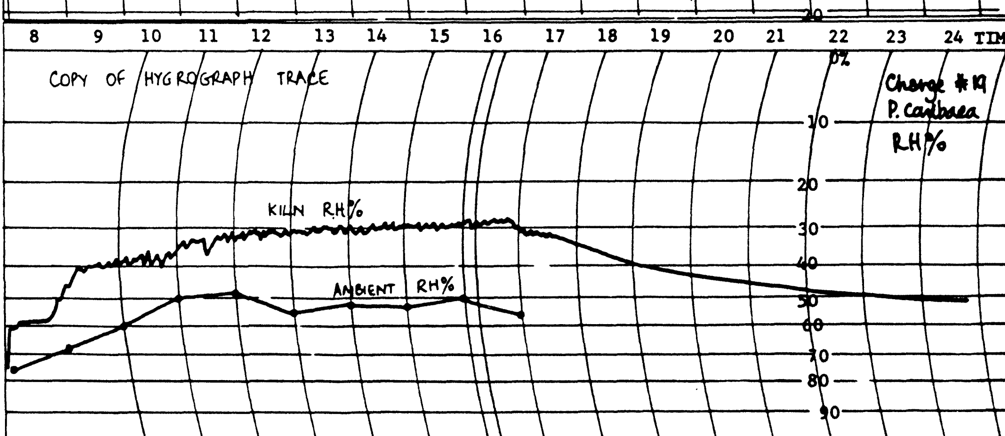
ADJUSTMENTS TO KILN: Air entry/exit flaps open 10cm at 0900 – shut at 1800.

OBSERVATIONS: Fans stopped at 1800 Hrs.

TIME	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	0800 (Next day)		
HOURS	0	1	2	3	4	5	6	7	8	9	10	11	12	
FUEL (10 litres)	||||| |||||	|||||		|||||		|||||	|||||	|||||	||||	||||	||||	/	/	/	/	
TOTAL FUEL x 10 litres	10	6	6	5	5	5	4	4	4	/	/	/	/	
AMB. DRY °C	22.5	24	25	27	27.5	26.5	27	27.5	27.5	27				
AMB. WET °C	19.5	20	20	20	20	20.5	20.5	21	20.5	21				
AMB. RH%	75	68	62	51	48	56	53	54	51	56				
WT. CONE SAMPLE	1298	1294	1281	1260	1256	1240	1226	1216	1206	1196		1177		
" LESS CONTAINER	945	941	928	907	903	887	873	863	853	843		824		
MC% OF CONES	24.3	24	22.9	21.2	20.8	19.4	18.1	17.1	16.2	15.2		13.2		
CONES CLOSED	6	6	6	4	4	4	4	3	3	3		2		
CONES HALF OPEN	19	19	18	17	16	15	13	11	10	9		2		
CONES OPEN	0	0	1	4	5	6	8	11	12	13		21		

*CONTAINER WT: 353 *OVEN DRY WT. OF SAMPLE: (Less container) 715 gms





Appendix 6

Factors Affecting Opening and Seed Extraction from Pinus oocarpa and Pinus caribaea Cones

The following list is a summary of factors affecting the opening of pine cones, and extraction of seed from them, as experienced in Siguatepeque.

1.	SHAPE OF CONE:	In *P. o.* long narrow cones open with more space between scales than short round cones, which facilitates seed extraction.
2.	MOVEMENT OF CONE:	Movement during drying improves seed extraction by: a. shaking seed out immediately it is free which.. b. enables other scales to open more. c. helps to break down resin seal around scales.
3.	MOISTURE CONTENT OF CONE	In *P. o.* cones dried very slowly may not open fully
4.	MATURITY OF CONE:	In *P. c.* immature cones tend to stick shut, or may not open at all, or else open from the tip only.
5.	INSECTS AND DISEASE:	Cones attacked by insects may be deformed, dried out, or the inside eaten out, so do not open completely. Resin exudation from infected parts can stick scales shut.
6.	SUN vs. KILN	Sun dried cones open irregularly on side exposed to sun and it is possible that individual scales open up more giving better release of seed. Kiln dried cones open uniformly all over, and depending on kiln temperature, the cone scales may reflex more than with sun drying.
7.	UNIFORMITY:	Factors such as 1,3,4 and 5 promote variation in drying and consequent lack of efficiency in using the kiln. Classification of cones could help.
8.	SPEED OF DRYING:	Overfast drying can produce case hardening and prevent cone opening.
9.	TEMPERATURE:	Normally, the higher the temperature,the better the opening (but see 8).
10.	AIRFLOW:	More airflow, the better the drying and hence opening. Airflow above a certain level does not produce further benefit since moisture can only be extracted at a certain rate.
11.	FLUCTUATION OF TEMP. AND RELATIVE HUMDITY:	Natural drying conditions fluctuate, and so fluctuating drying regimes might help open cones better than constant regimes.
12.	OVERDRYING:	If cones are overdried, the upper scales reflex onto lower scales, and may trap seed that has not already fallen out.

Appendix 7

Construction and running costs of kiln

The following costs are estimated, based on values in Honduras for 1982.

Construction costs: U.S. $			Totals	
Item	Unit	Quantity	Material	Labour
Foundations	m (linear)	15.5	77	65
Floor	m^2	14.5	168	69
Walls	m^2	29.5	354	300
Roof - normal	m^2	16.0	368	192
(or: - solar (2 layers))	(m^2)	(32.0)	(552)	(384)
Ceilings and ducts	m^2	28.0	200	100
Partitions	each	3	150	80
Doors and flaps	each	5	150	80
Trays (89 x 89 cm)	each	64*	512	256
Fans	each	2	68	150
Axles, belts, pulleys	as req.		100	-
Motor (electric)	each	1	400	-
(Generator)	(each)	(1)	(700)	-
Furnace	each	1	500	250
Radiator 4 round tube	each	1	225	112
or: (2 round tube)	(each)	(1)	(400)	(112)
or: (2 galv. iron)	(each)	(1)	(60)	(40)
Regulator	each	1	30	60
Chimney	each	1	15	20
Thermograph	each	1	250	-
Other (10%)			356	171
	Total	5828 US$** =	3923 +	1905

* This is the minimum no. required. For practical use, a further 64 trays are needed for preparing new charges, plus sufficient to cover precuring requirements (64 x no. of days precuring required)

** Total cost using mains electricity, normal roof, 4 tube radiator

Running costs: U.S. $ per HOUR				
Item	Unit	Quantity	Cost/unit	Total
Electricity for fan	kwh	1	0.08	0.08
(Fuel for generator)	gal.	0.5	(2.00)	(1.00)
Fuel for burner (firewood)	litre	24	(0.005)	(0.12)
Maintenance	(1000 hrs/yr Total/yr = 200)			0.20
Depreciation	(5828 x 10%/1000 hrs/yr)			0.58
Labour (1 operator)	hr.	1	1.25	1.25
Total (cone fuel, mains electricity)	2.11 US$			
(Generator, firewood)	3.15 US$			

Appendix 8

Solar kiln experimentation (See fig. on opposite page)

The first solar kiln constructed at ESNACIFOR was based on a convection design used for drying agricultural produce (Anon 1975). The kiln was made from a framework of wooden battens, covered with transparent polythene (standard quality, 4 mil). A heat absorber, made from corrugated galvanised iron, painted matt black, was placed in the air entry duct at ground level, and a linear chimney, with the rear wall painted black, provided the convection required. Flow of air through the trays was slow and not uniform, and little benefit was derived over direct exposure to the sun.

The second kiln (Mk. 2) was also built from battens and polythene, but followed the overall design of the Oxford forced draught timber drying kiln (Plumptre 1979) substituting trays and baffles for the timber stack, and circulating air by means of two large diameter fans turned by pedal power. The energy performance of the kiln was as expected, but airflow limited to the physical capabilities of the pedaler (consumption of Pepsi-Cola was high).

However, the kiln appeared promising, and was dismantled and incorporated into a more sophisticated model (Mk.3). The main walls of this kiln were prefabricated from wood tongue and groove boarding, with only the roof of plastic so as to reduce expense and time in replacing the polythene. Some special features were tried, such as adjustable airflow either side of the absorber, a heat sink made from bricks with the object of evening out temperature fluctuations, and eventually a back-up artificial heating system was included, which was the forerunner to the Mk.4 system.

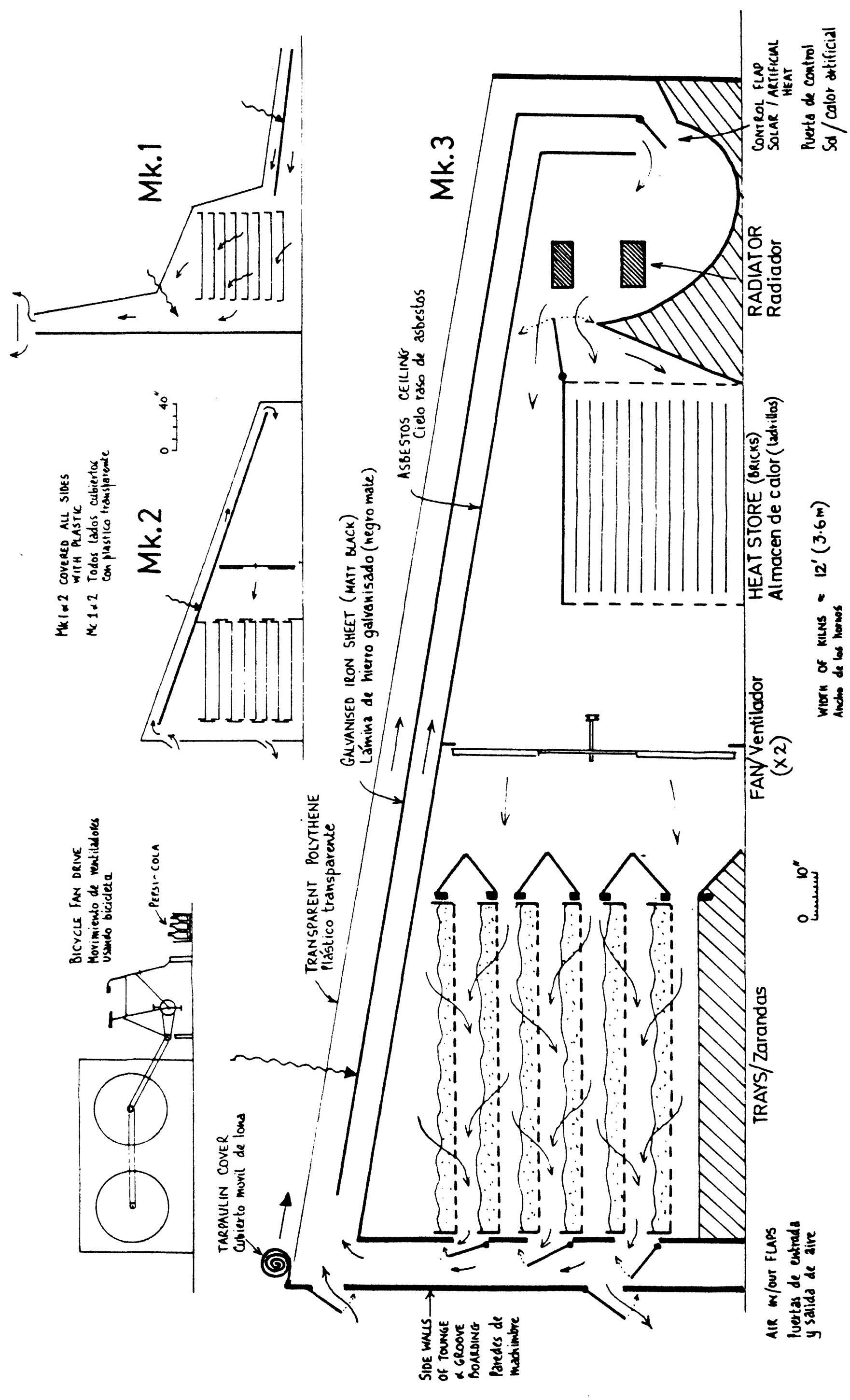
After several studies, it was concluded that cone opening was almost as fast if the cones were exposed directly to the sun, and that the kiln was of little value on cloudy or rainy days. Although drying continued during these period, it did not provide adequate opening of the cones. The supplementary heater introduced to overcome this problem demonstrated that waste cones yielded more than enough fuel to dry each charge, and was simple to use.

It was therefore decided that further kilns should use the artificial heat source alone, and thus be suitable for operation day and night, and in any weather condition. However, the concept of augmenting the effectiveness of the sun for drying was not discarded altogether, and it appears that the best method is to expose the cones to the sun on the trays under a transparent roof thus making use of the simple greenhouse effect for increasing temperature and avoided the need to move the trays when raining. Such systems are used in Zimbabwe (Seward 1980) and Thailand (Bryndam 1975). The main obstacle still remains the supply of suitable, cheap, resistant transparent plastic for the large areas involved. Almost all sundrying at ESNACIFOR continues to be done by direct exposure of the trays in the open, moving under cover when rains occur or at night.

The Mk. 3 kiln was modified to use artificial heating only, and transferred to Culmí, Olancho. Since no electricity was available, attempts to run it using pedal power were tried. However, air flow was not satisfactory, and the proper operation of the kiln awaits funds to enable connection to the local electricity supply, or purchase of a suitable generator or engine.

The Mk.3 kiln has demonstrated the feasability of construction from prefabricated panels, which could be used for the MK. 4 kiln if it was to be erected temporarily in a remote area.

ESNACIFOR SOLAR KILNS/ Hornos solares



ESNACIFOR CONE KILN

TECHNICAL DATA SUMMARY

GENERAL:

- Batch type kiln, using forced ventilation and artificial heating, with a capacity for 3200 litres of cones.

BUILDING:

- Length 155" (393 cm), Width 155" (393 cm), Height (ex. roof) 98" (249 cm).
- Volume of moveable air in kiln 32 m^3
- Materials: Brick, plywood, timber, galvanised iron.

VENTILATION SYSTEM:

- Fan Type:	Propellor, 8 bladed, 60" (152 cm) diam. x2
- Drive:	1 hp electric motor, via pulleys and v-belts. Gasoline or diesel engine may be used.
- Fan speed:	250 rpm
- Volume of air moved per fan:	1.2-1.75 m^3/s
- Airspeed past cones:	0.31-0.44 m/s
- Airspeed past radiator:	2.5. m/s
- Air exchange:	Inconnected flaps permitting single pass of air, or complete recirculation.

HEATING SYSTEM:

- Burner type:	Simple brick and concrete with iron doors.
- Burner size:	(internal) l. 32" (81 cm), w. 13.5" (34 cm), h. 32" (81 cm)
- Radiator:	Flue gas; three possible types: (i) 4 x 4 round steel tubes (surface area = 7238 sq" (46699 cm^2) (ii) 2 x 6 round steel tubes (surface area = 5428 sq" (35031 cm^2) (iii) 2 x rectangular 10" x 6' (surface area =7776 sq" (50170 cm^2)
- Regulator:	Manual control, enabling radiator to be bypassed and chimney damped.
- Temperature control:	Manual, by observation of thermograph, and operation of regulator to suit.
- Temp. precision	+/- 1°C
- Max Temp.	Approx. 80°C
- Fuel Type:	Waste cones, firewood etc.
- Fuel consumption:	P.oocarpa cones: 40-60 litres of open cones/hr. P.caribaea cones: 80-120 litres of open cones/hr.

TRAY SYSTEM:

- General:	Trays used are stacked on wheeled plat forms, and are used for sundrying and precuring also.
- Size:	35" (89 cm) square, capacity 50 litres of closed cones
- Number:	64, giving a total capacity of 3200 litres closed cones.

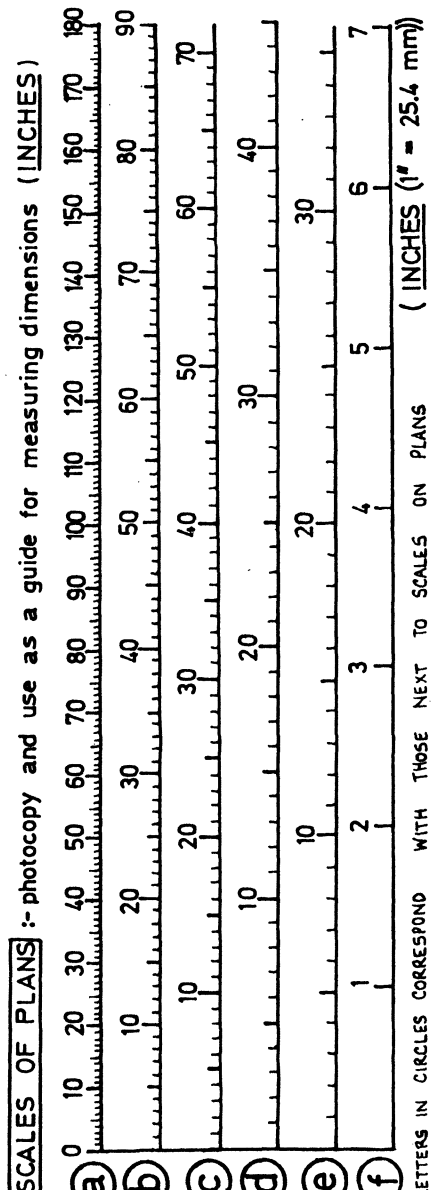
The complete kiln can built from local materials at a cost of approx. U.S.$.6000.

ESNACIFOR CONE KILN PLANS

(DRAWN BY THE AUTHOR)

SCALES

KEY (FIG 1 ON PAGE 3 OF TEXT)



KEY TO FIGURES 2-11

Figs: 2,3,4,5,8

A Fan partition
B Air entry partition
C Air exit partition
a Top wall batten
b Main ceiling support (50 x 100mm)
c Main ceiling panel (8mm plywood)
d False ceiling support (50 x 100mm)
e False ceiling panel(8mm plywood)
f Air exhaust flap
g Air intake flap
h Interconnecting cord
h' Flap adjuster
i Main door
j Fan access door
k Panels (8mm plywood)
m Upper radiator ducting (galvanised iron sheet #26)
n Lower " " "
p Radiator cowl "
q Radiator wall (brick)
r
s Panel ceiling battens (25 x 50mm)
t Access hatch for radiator
u Exit partition louvre (8mm plywood)

Fig. 9

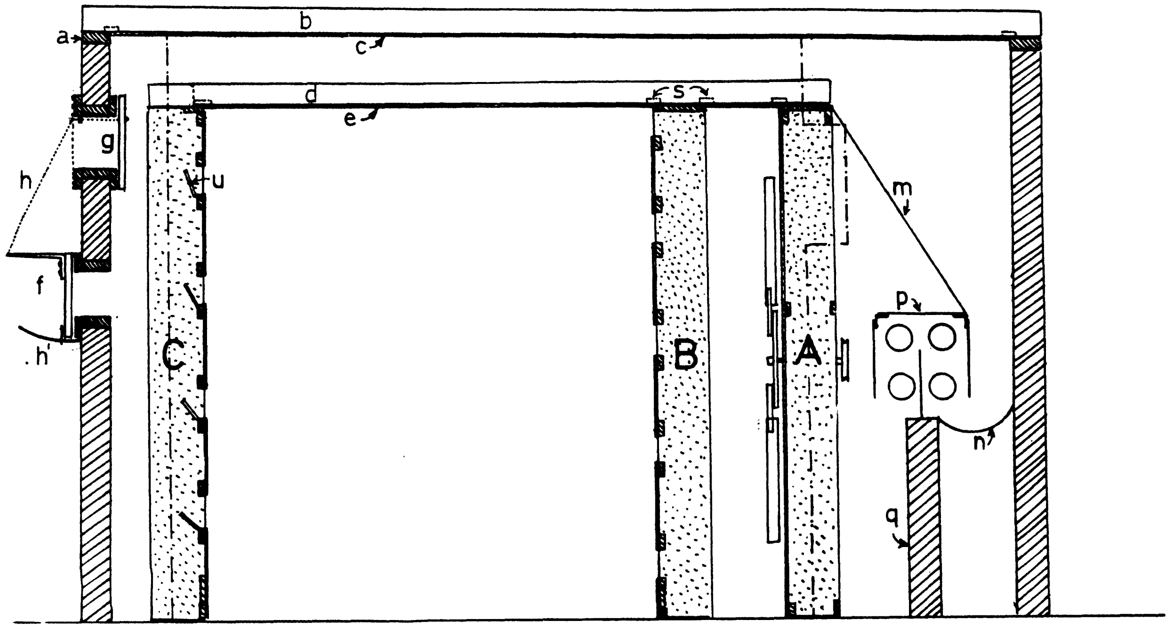
a Standard brick
b Refractory brick
c Flue exit (6mm steel sheet)
d Fixed door panel "
e Main fuel door "
e' Main fuel door catch handle
f Ash/air door "
f' Ash/air door adjuster "
g,g' Door supports
h Support bolt fixing
i Main door catch
j Main door catch guide
k Main door hinge
m Ash door hinge

Fig. 10

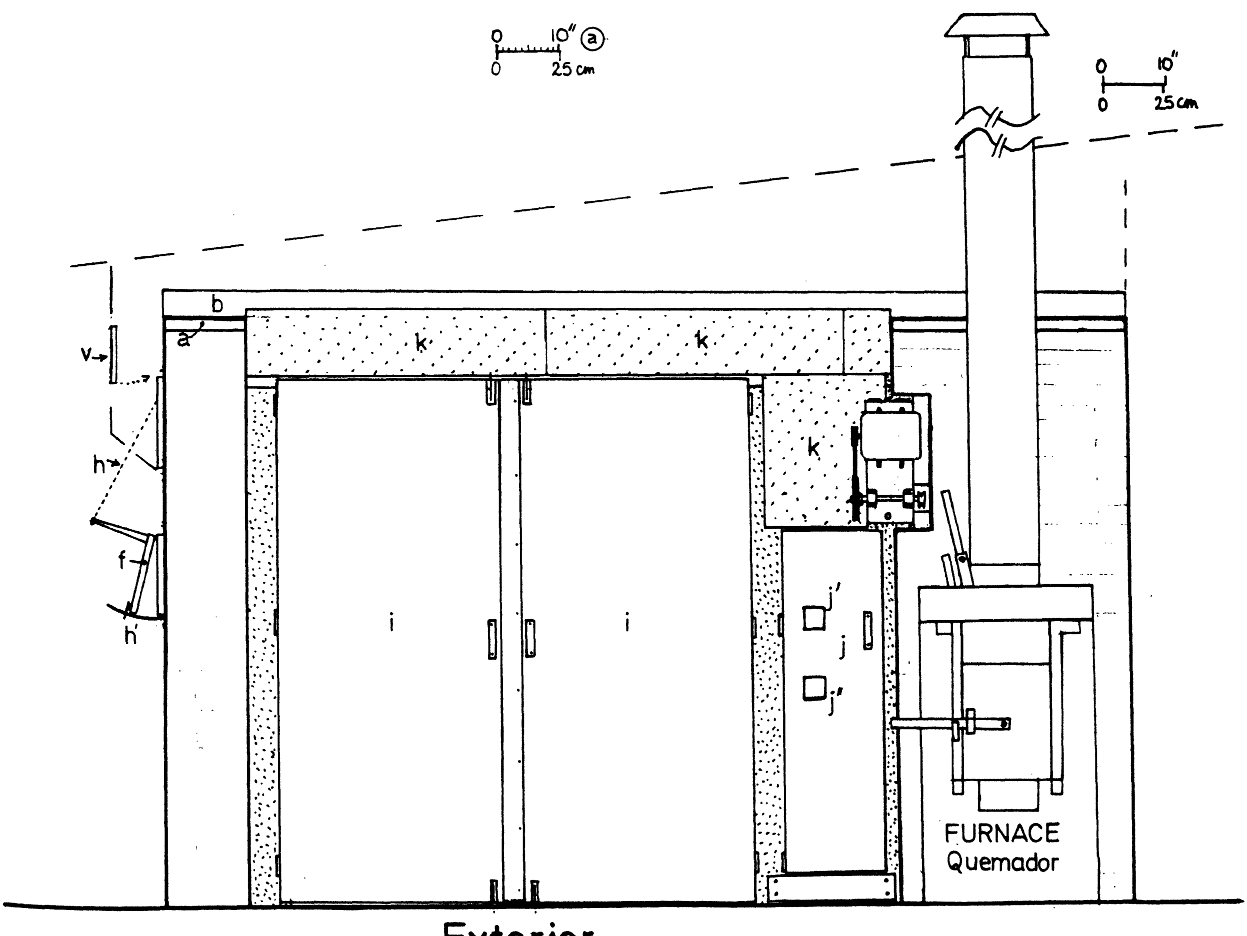
A U-bend (section, side view)
B U-bend (front view)
C Radiator tube (section)
D Regulator (rear view) (6mm steel sheet)
E Regulator (section, side view)
F Regulator (exploded diagram)
G U-bend (exploded diagram)
H U-bend (plan view)
a Burner flue exit
b Regulator body (6mm steel sheet
c Radiator control lever
c' Radiator control flap
d Chimney control lever
d' Chimney control flap
d'' Chimney control adjusting screw
e Tube threaded coupling (100mm (4") diam.)
e' Tube threaded coupling (150mm (6") diam.)
f Chimney
g Radiator tube (100mm (4") diam)
g' Radiator tube (150mm (6") diam)
g'' Radiator tube (rectangular, galv. iron 24g)
h U-bend sleeve (galv. iron 24g)
i U-bend (6mm steel sheet)
j Removeable cover (galv. iron)
k Radiator access hatch
m Upper radiator ducting (galv. iron)
n Lower radiator ducting (galv. iron)
n' Angle iron support (35mm)
n'' Tubular support
p Radiator cowl.

FRONT VIEW / Fachada principal Fig. 2

ESNACIFOR CONE KILN



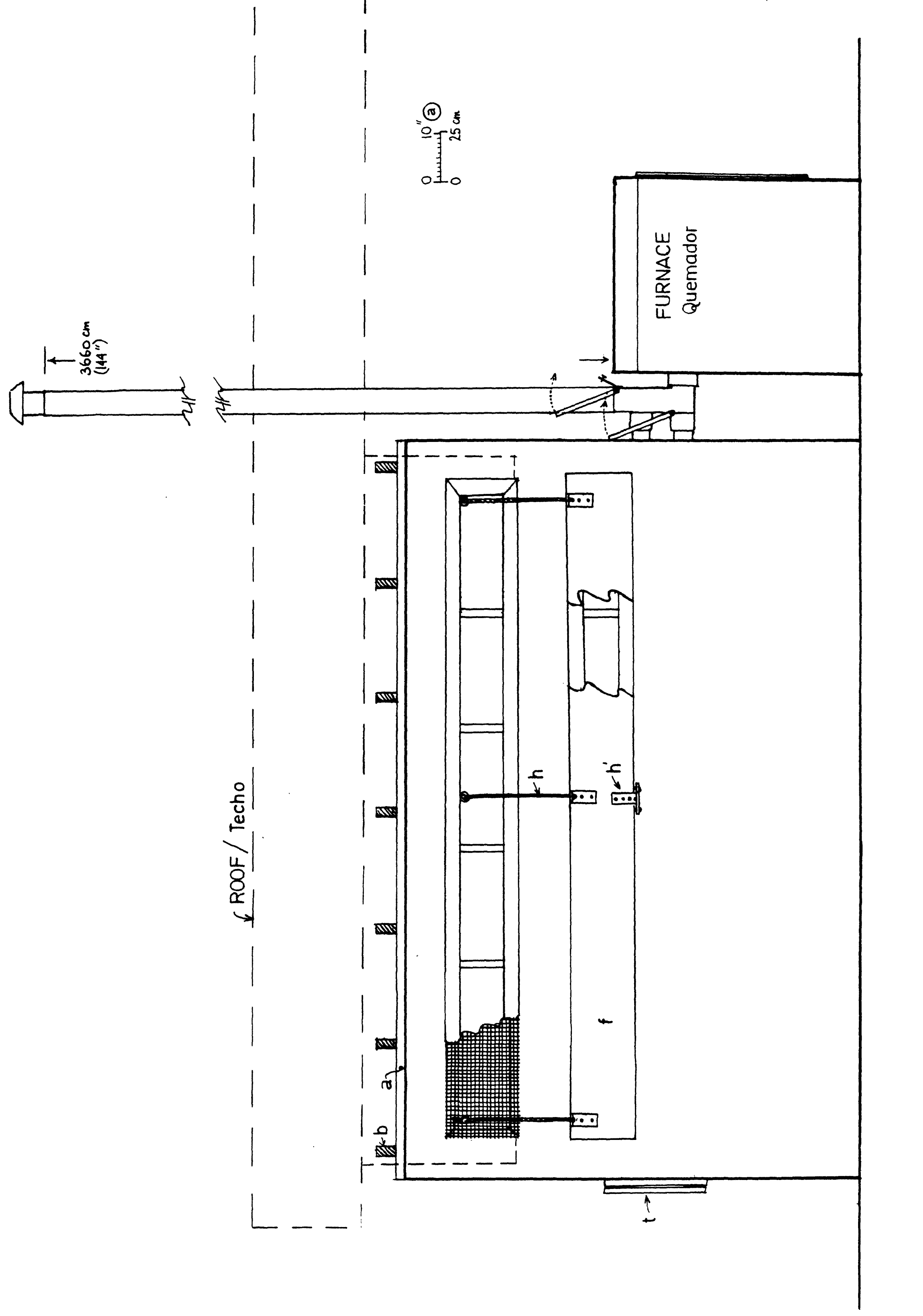
Interior



Exterior

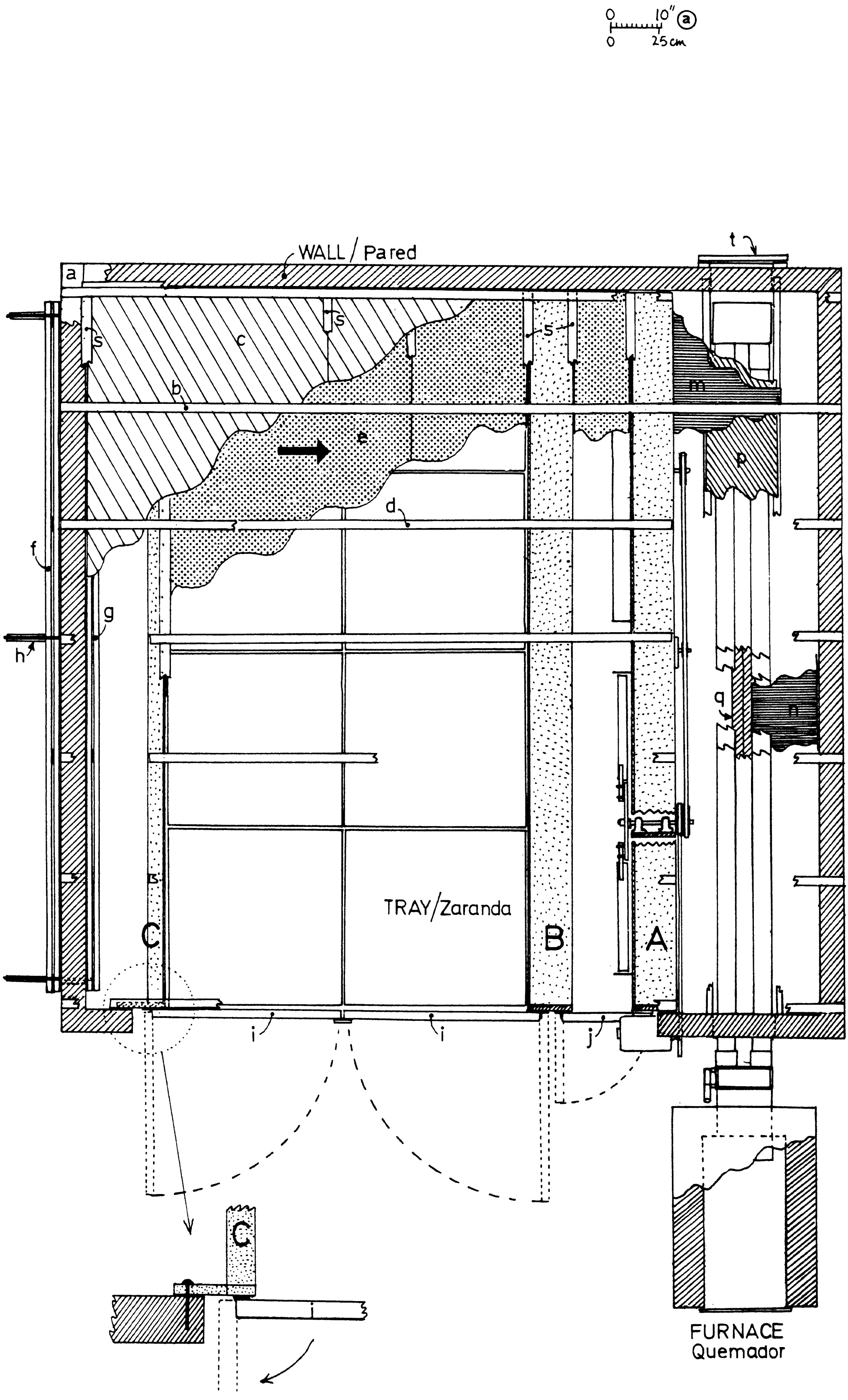
SIDE VIEW / Elevación lateral Fig. 3

ESNACIFOR
CONE KILN



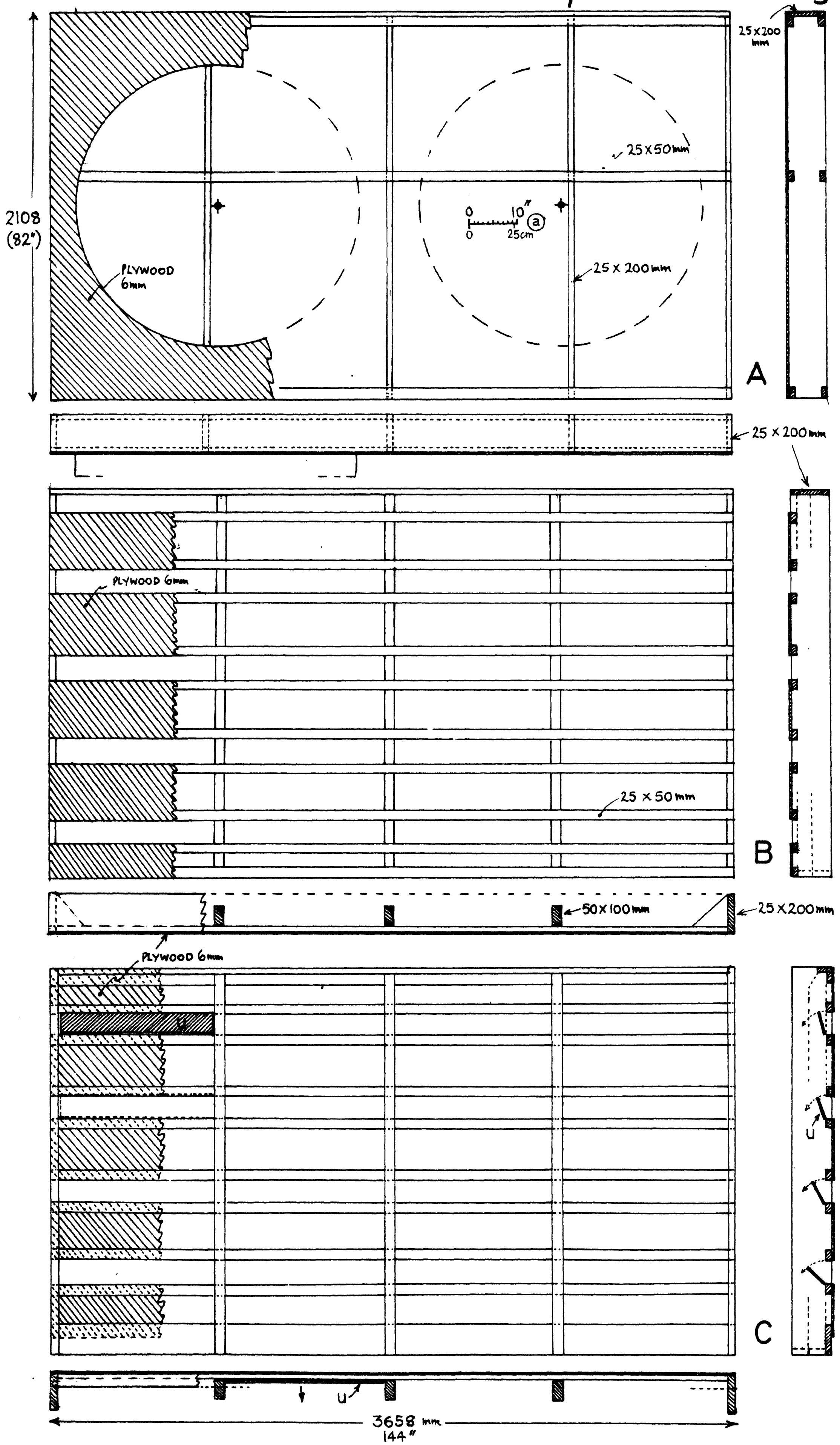
PLAN/ Planta Fig. 4

ESNACIFOR CONE KILN

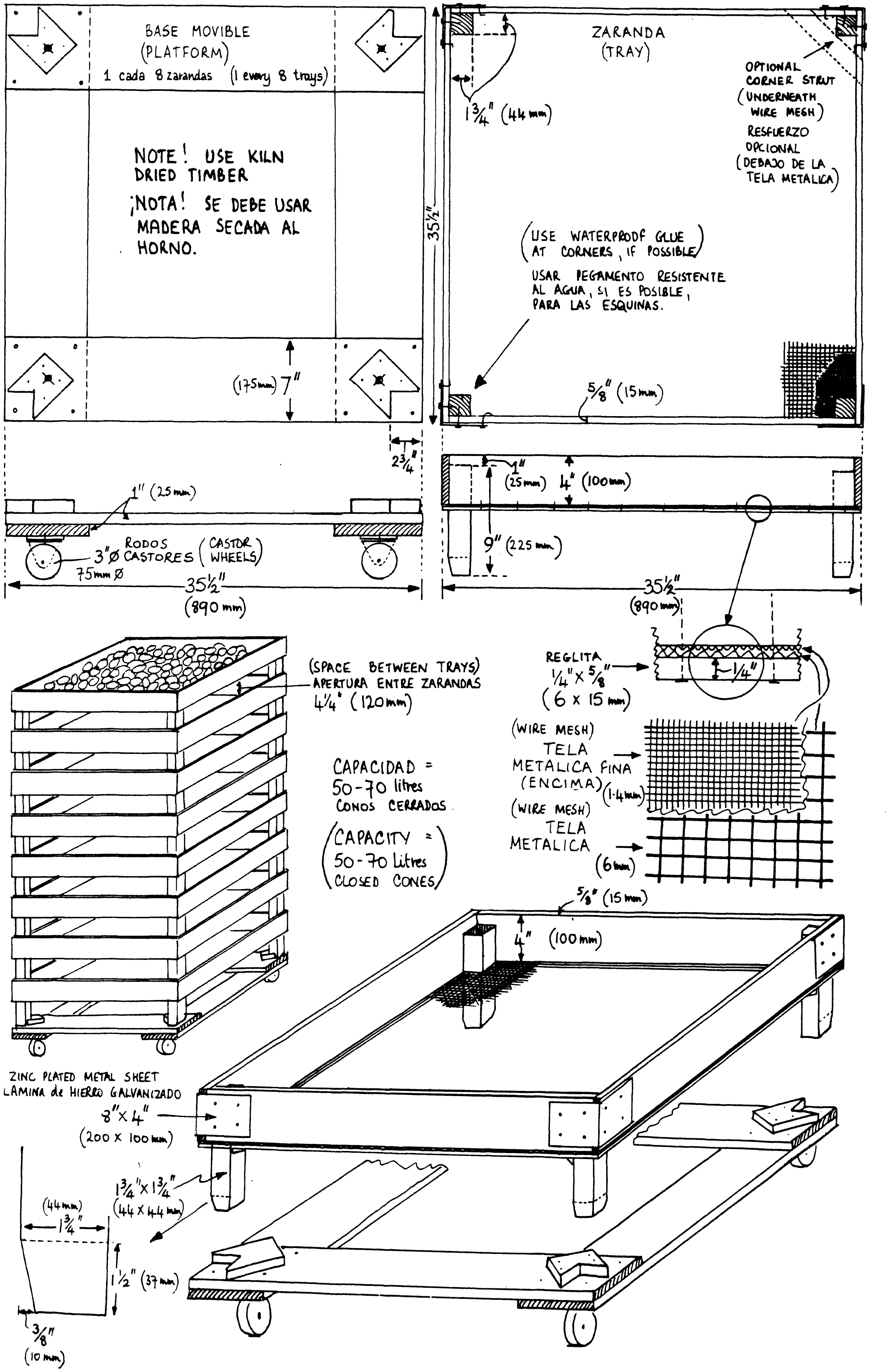


ESNACIFOR CONE KILN

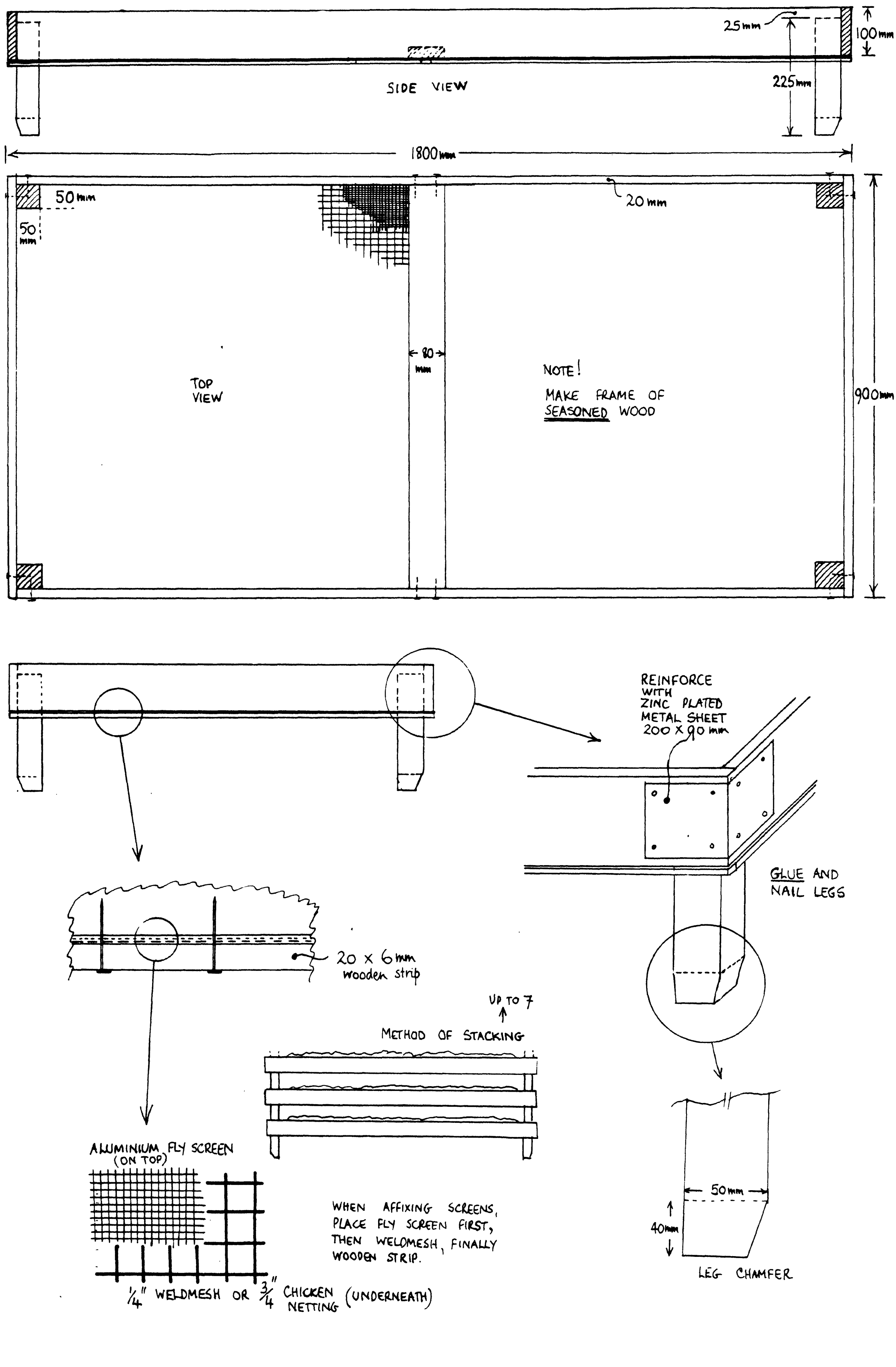
PARTITIONS / Divisiones Fig. 5



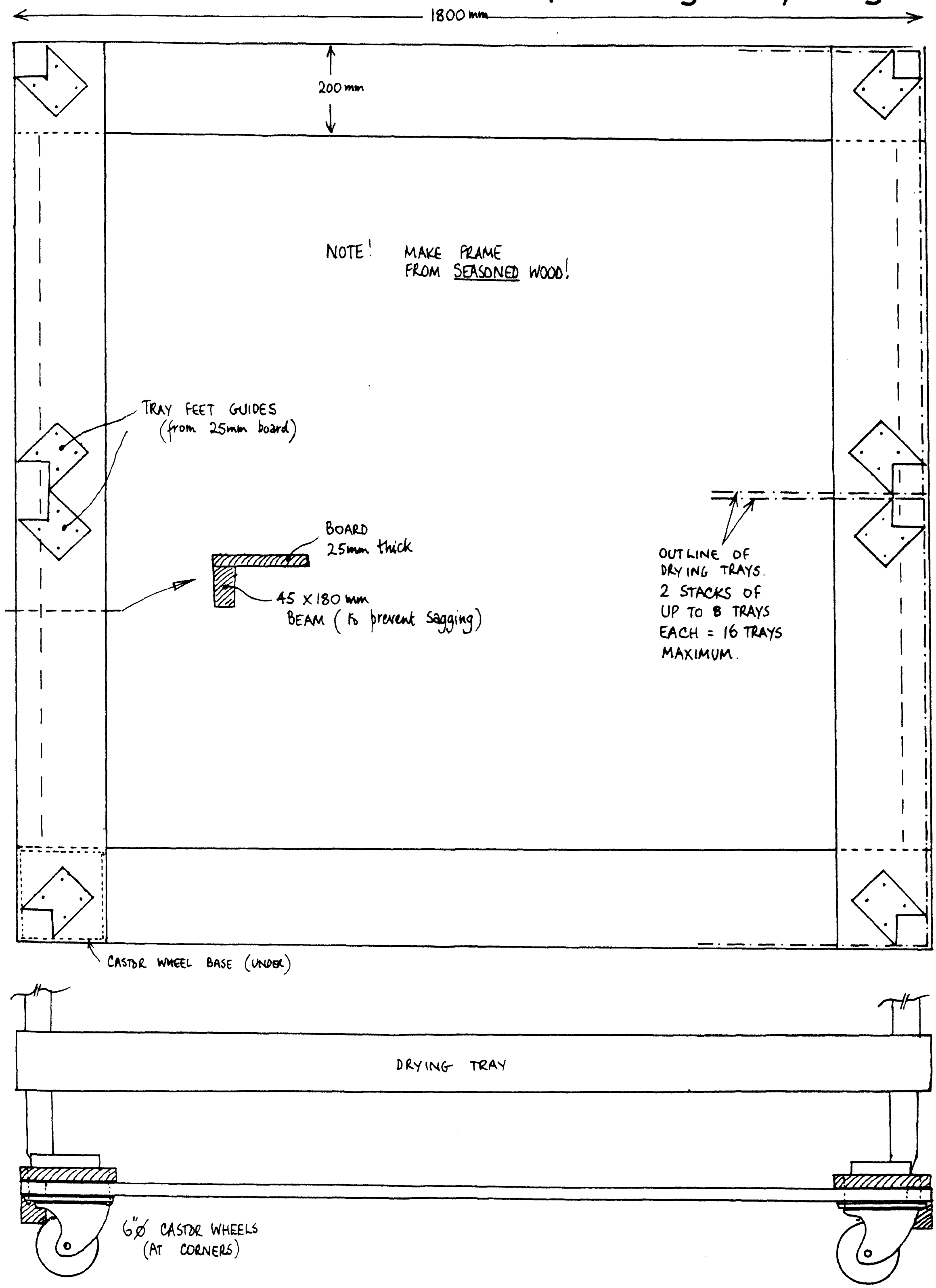
DRYING TRAY/ Zaranda (50 litres) Fig. 6a



DRYING TRAY / Zaranda Fig.6b (100 litres)

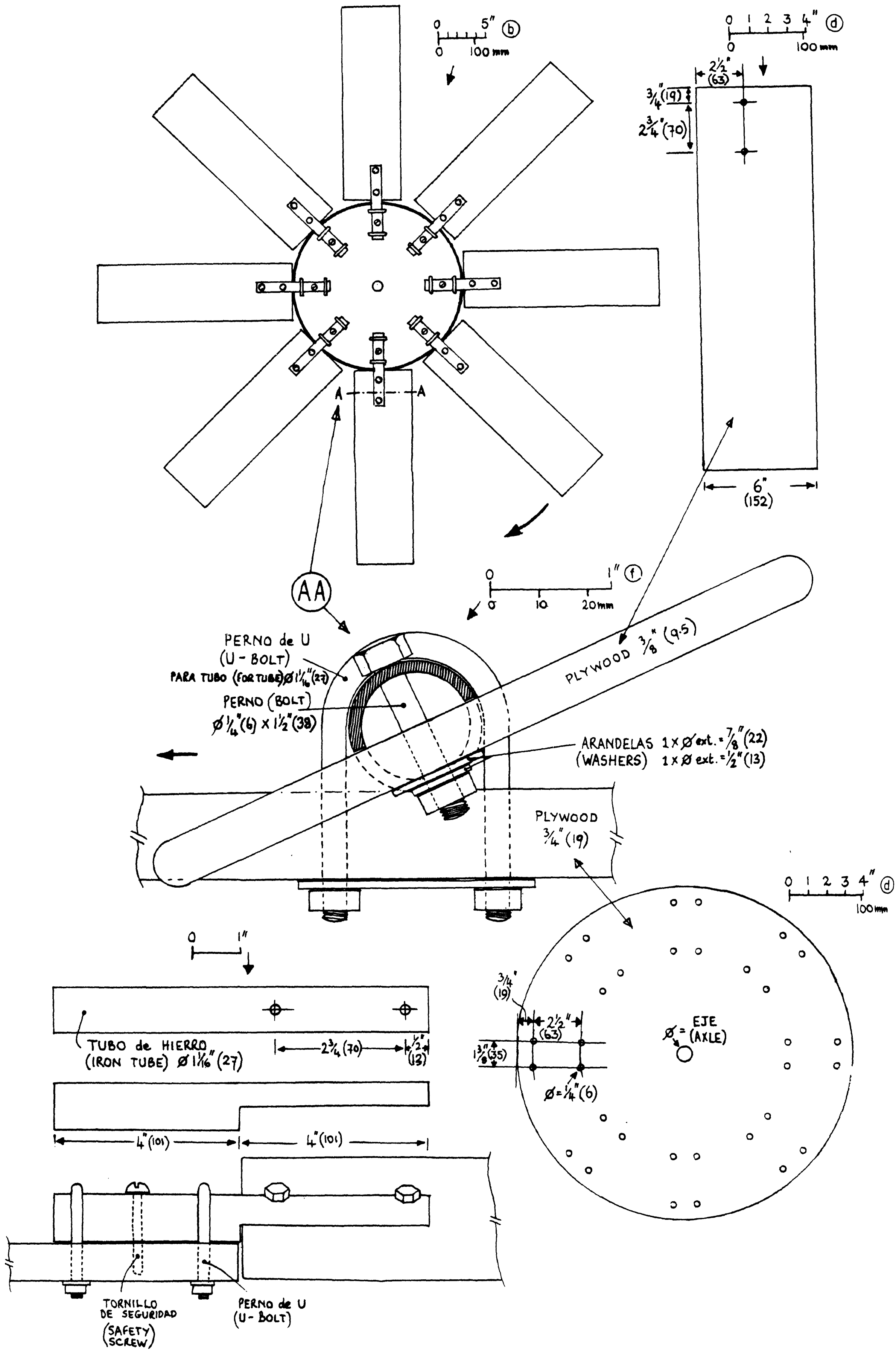


PLATFORM / Plataforma (LARGE / grande) Fig.6c



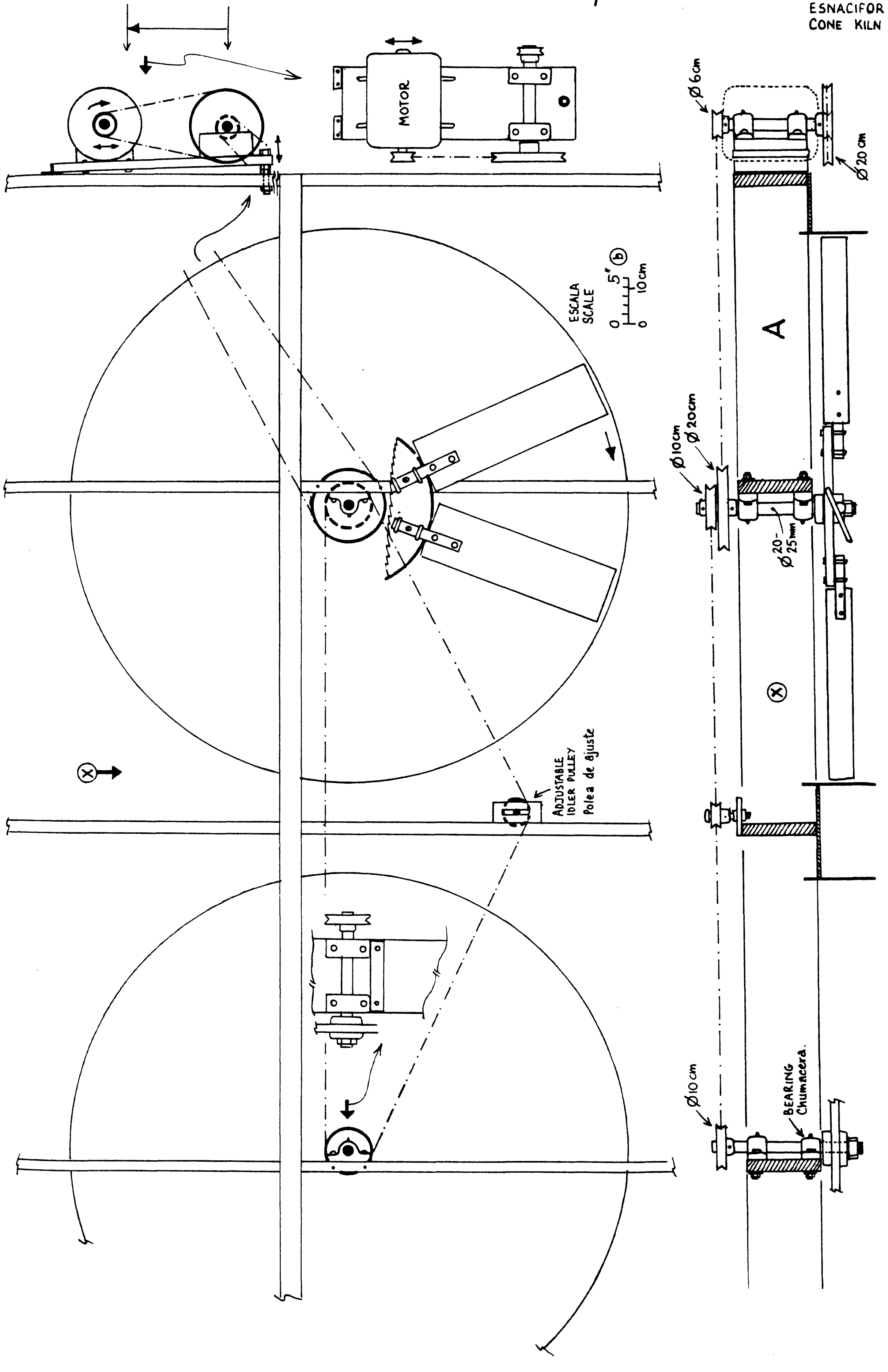
FAN / Ventilador

Fig. 7
ESNACIFOR
CONE KILN



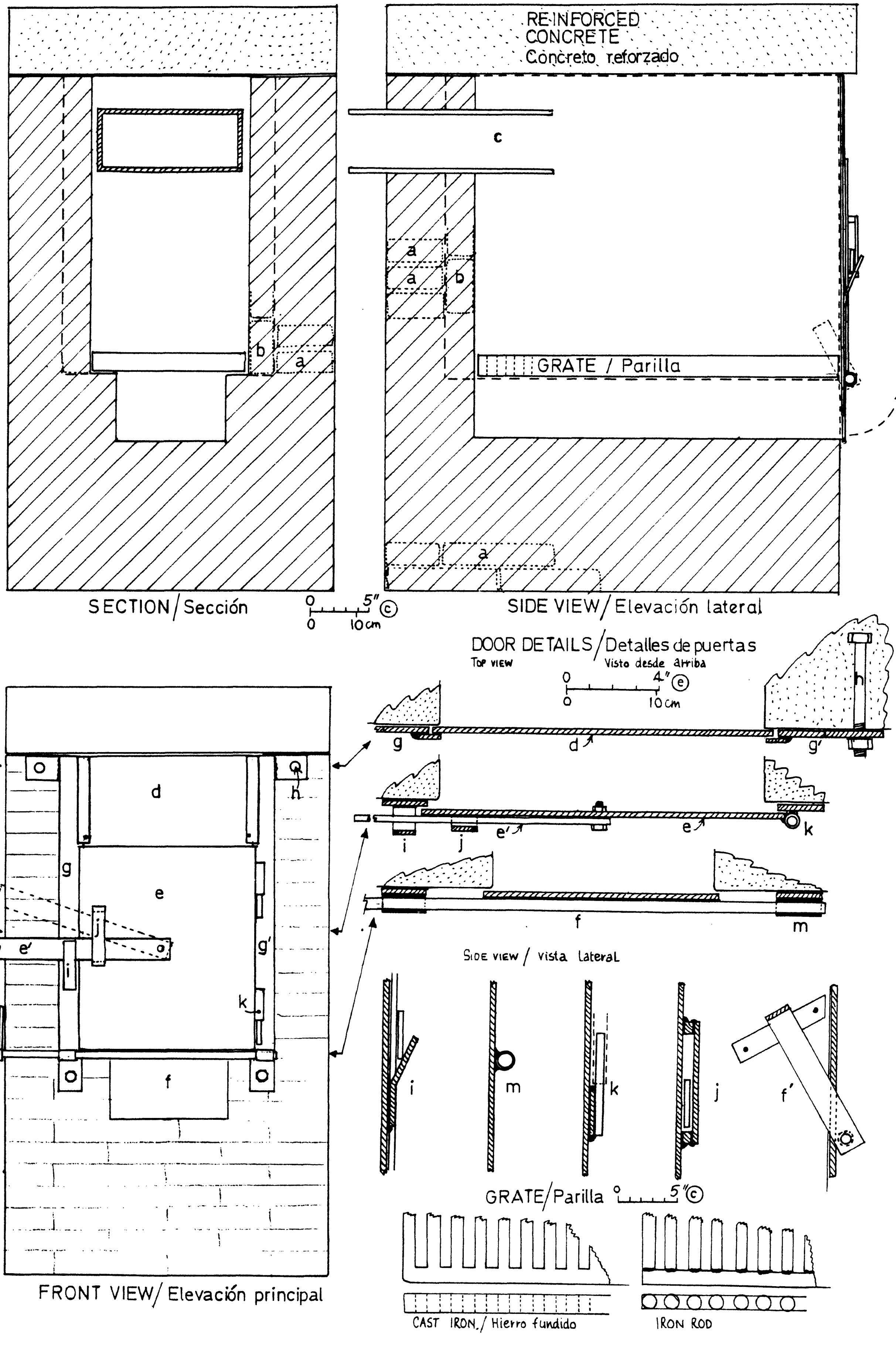
FAN DRIVE / MOVIMIENTO DE LOS VENTILADORES Fig. 8

ESNACIFOR
CONE KILN



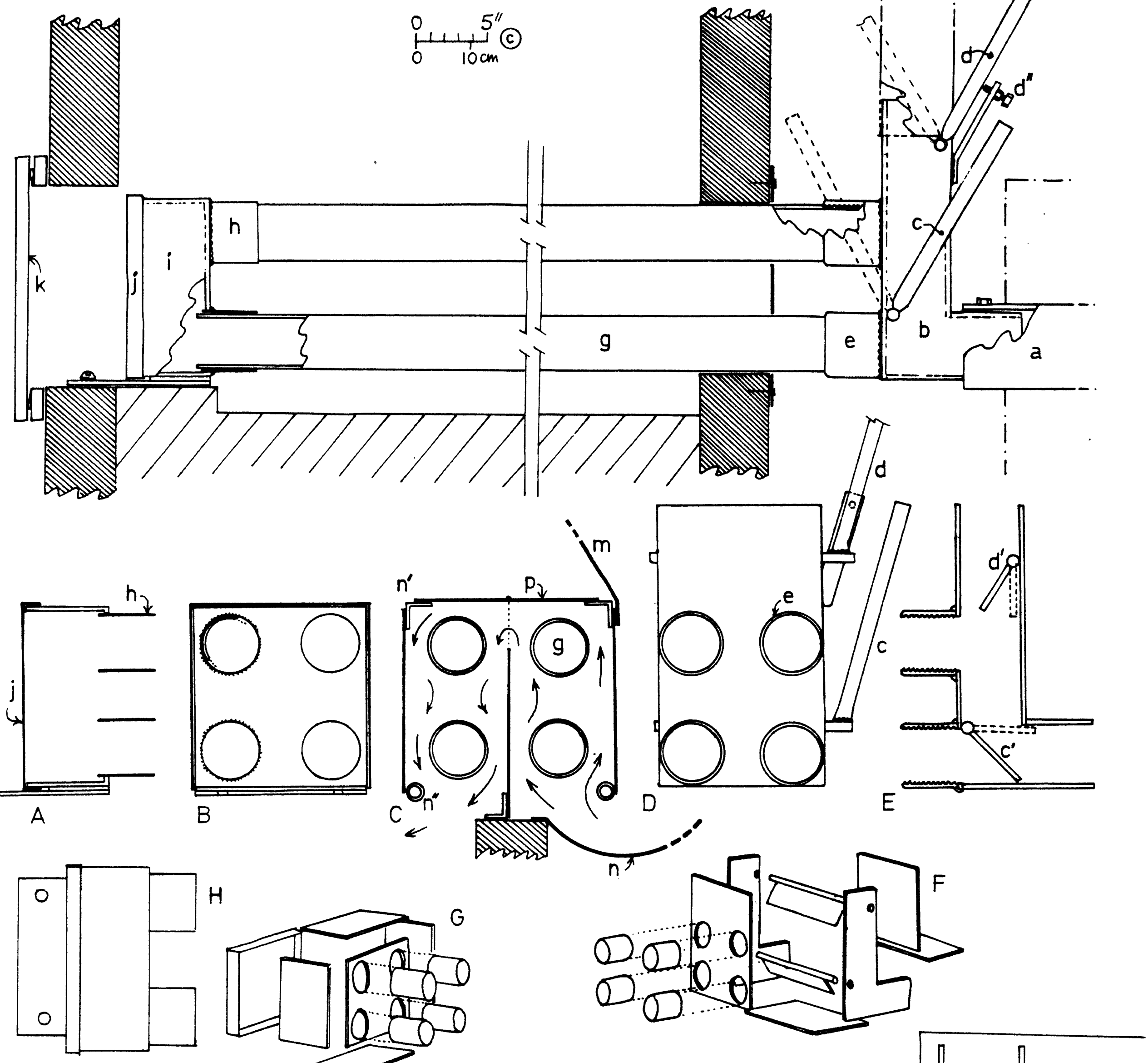
FURNACE / Quemador

Fig. 9
ESNACIFOR
CONE KILN

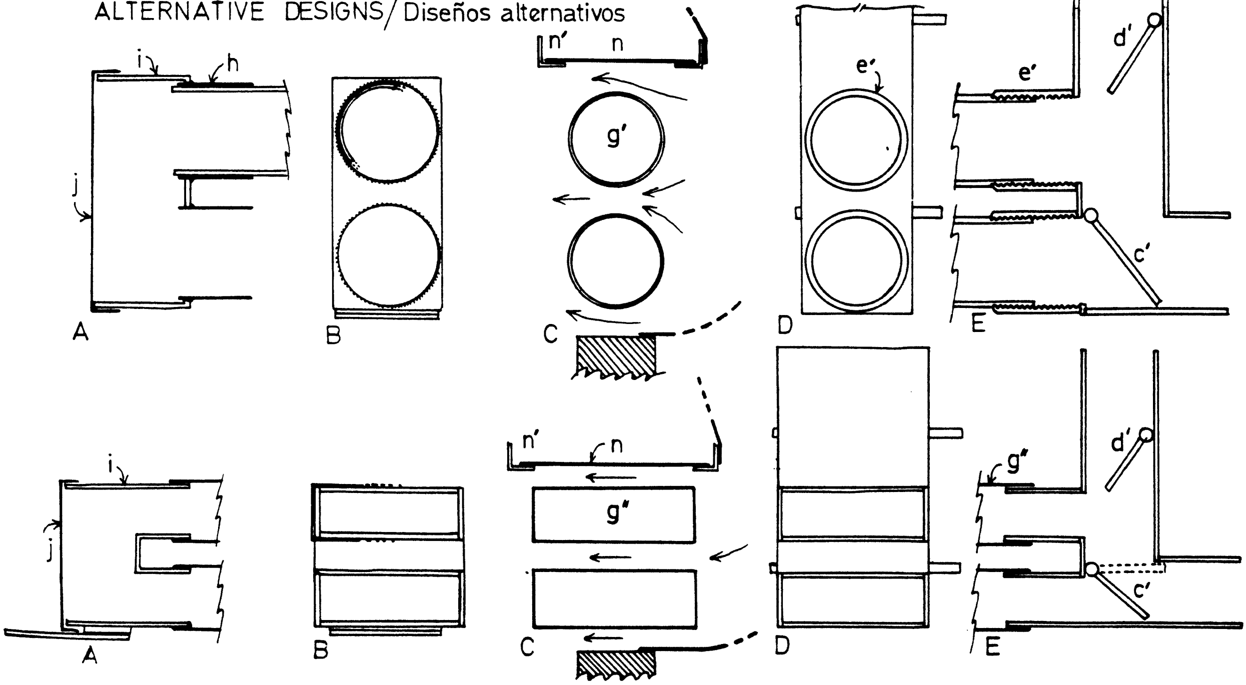


ESNACIFOR CONE KILN

RADIATOR / Radiador Fig. 10



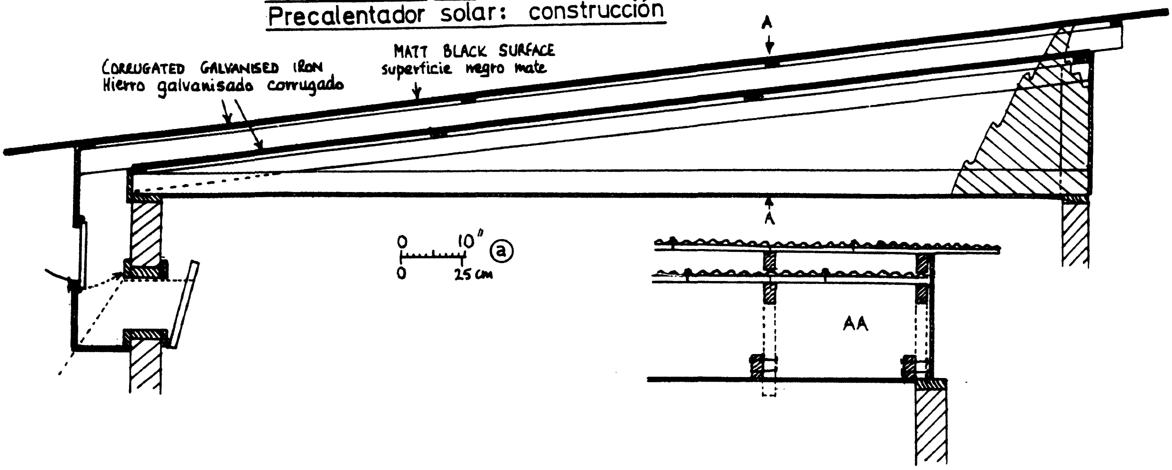
ALTERNATIVE DESIGNS / Diseños alternativos



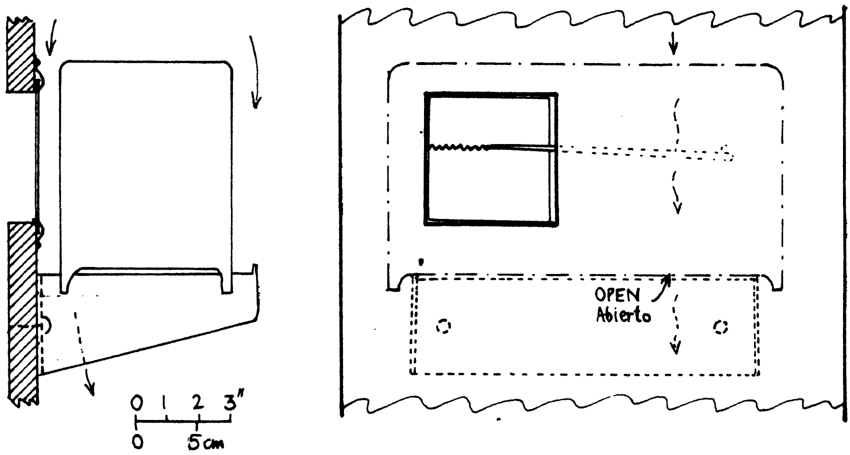
MISCELLANEOUS / Miscelánea

Fig. 11
ESNACIFOR CONE KILN

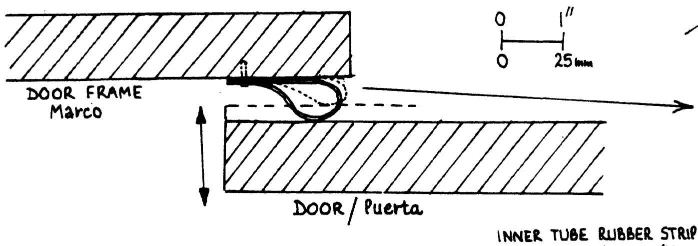
SOLAR PREHEATER CONSTRUCTION
Precalentador solar: construcción

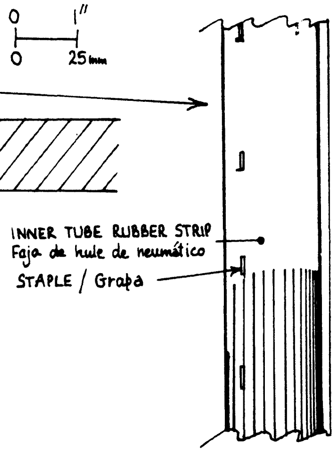


THERMOGRAPH SUPPORT / Soporte para thermograph

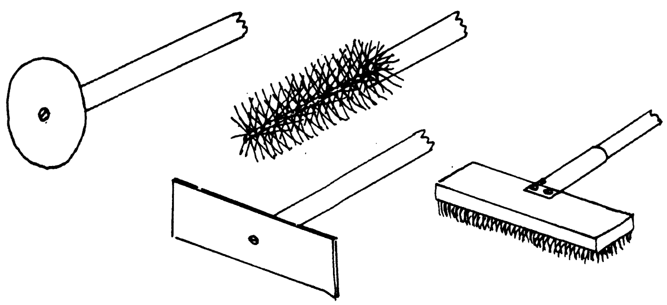


DOOR SEALS / Sellos de puertas





FLUE CLEANERS
Limpiadores para tubos



ESNACIFOR CONE KILN MANUAL

OPERATING INSTRUCTIONS

MAINTENANCE

FAULT GUIDE

DRYING REGIMES

CONSTRUCTION NOTES

OPERATING INSTRUCTIONS

Load kiln

1. Prepare and install thermograph
   (a) check accuracy with thermometer
   (b) mark temp. limits on graph
   (c) attach graph paper
   (d) check supply of ink
   (e) install and ensure operation OK
   (f) adjust to correct hour

2. Check louvres in exit partition in correct position (before loading the kiln), and air flaps adjusted (see regime section)

3. Start fans and check operation

4. Light up furnace, ensuring that
   (a) radiator control shut
   (b) chimney control open
   (c) fuel door shut
   (d) ash door open

5. When fire in properly burning, and chimney is heated (check chimney thermometer (100 - 200°C)), check adjustment of chimney control when closed: adjust screw so that smoke is just prevented from issuing from fuel door.

6. The kiln can now be heated with
   (a) radiator control open
   (b) chimney control open (as before)

7. Observe thermograph and check that heatup time is normal (if not, see fault section). Ensure continuous supply of fuel. A drop in the rise of temperature will indicate that more fuel is needed.

8. When upper temperature limit is reached, stop heating by putting:
   (a) radiator control shut
   (b) chimney control shut (see 5)

9. The kiln will now cool. When the lower temperature limit is reached (observe thermograph), the kiln is heated again, putting:
   (a) radiator control open
   (b) chimney control open

   Observe thermograph or burner to see if sufficient fuel is remaining to heat. If not, add more fuel. Note that to heat it is not always necessary to add more fuel: there may be enough (see following notes)

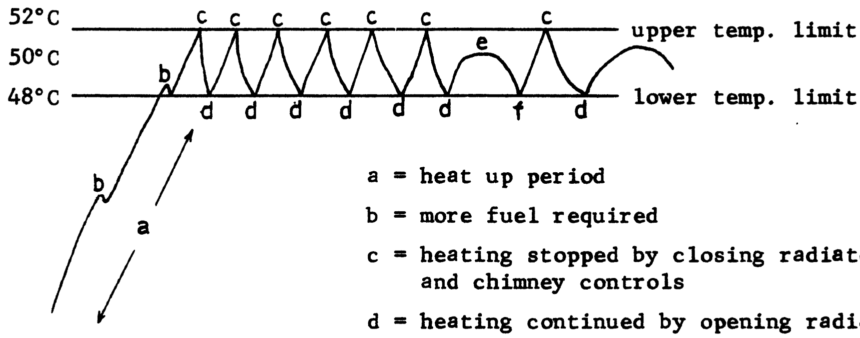
10. Continue following points 8 and 9, keeping the thermograph trace within the limits set.

NOTES:

The frequency of operation of the radiator and chimney controls will depend principally on the mean temperature desired, the temperature limit range, and the rate of stoking.

The rate of stoking will depend on many factors
(a) ambient air temperature (colder - more fuel)
(b) Mean temperature of kiln (hotter - more fuel)
(c) Rate of air exhaust from kiln (quicker - more fuel)
(d) Type of fuel (lower calorific value - more fuel)
(e) Period of operation of kiln (longer - less fuel)
(f) Moisture content of load (higher - more fuel)

For maximum fuel economy the operator should aim at a stoking rate that is just sufficient to reach the upper temperature limit, without excessive use of the radiator control to cut the heat off. An ideal rate almost avoids the need to use the radiator control, but can only be obtained with practice. An example trace is as follow:



a = heat up period

b = more fuel required

c = heating stopped by closing radiator and chimney controls

d = heating continued by opening radiator and chimney controls (and, if necessary, stoking)

e = heating stopped due to lack of fuel (radiator and chimney controls still open)

f = heating continued by stoking (radiator and chimney controls still open). Note that there may be a time lag, and the trace may fall below the minimum limit. The solution is to stoke before trace reaches lower limit.

The actual trace recorded will depend on the type of fuel. Pine cones will give a trace similar to the above. Firewood, which is slower burning, will give slower heating. Cooling will generally be at the same rate, irrespective of fuel type, all other factors being equal.

If a fast burning fuel is used, the burner ash door can be closed to limit air intake and reduce burning rate.

It is best to stoke little and often. If *P. oocarpa* cones are used as fuel, for example, stoke with a shovelfull at a time (= 10 litres of open cones) - when the kiln is cold, about 600 litres are required/hour (1 shovelfull every 8 minutes), reducing to 400 litres/hour when the kiln is warm (1 shovelfull every 15 minutes)

A new operator should be able to keep within +/- 2°C limits of the required mean temperature, which is precise enough for most regimes. With a little experience, +/- 1°C is easily possible.

If for some reason, the kiln temperature passes the upper limit, and cannot be cooled quickly enough by closing the radiator control, open the air intake/exhaust flaps to introduce cool ambient air.

Electricity Failure

If the electricity fails, the fans will stop and the radiator will not be cooled. Therefore, to avoid overheating of the tubes and adjacent parts of the kiln:

(a) shut radiator control
(b) shut chimney control

FIRE!!!!! ALWAYS KEEP AN EXTINGUISHER OR BUCKETS OF WATER AVAILABLE

IF FIRE OCCURS WITHIN THE KILN:

(1) SWITCH OFF FANS, SHUT RADIATOR AND CHIMNEY CONTROLS
(2) KEEP ALL DOORS AND FLAPS SHUT UNTIL READY TO FIGHT FIRE
(3) IF EXTINGUISHER OR WATER AVAILABLE, OPEN APPROPRIATE DOOR AND TRY TO DOUSE FLAMES
(4) IF POSSIBLE, REMOVE DRYING TRAYS.

Every charge or 24 hours of operation	(a) check thermograph operation and ink supply (b) remove ash from furnace
Every 5 charges or 90 hours of operation (or more frequently)	(a) clean radiator and chimney. Remove radiator access panel, clean upper tube(s) with brush, pushing soot into regulator. Shut radiator control and allow dirt to fall into lower part of regulator. Clean lower tube(s), pushing all soot through into burner. (b) check fan mountings, belt tension, pulleys.
Every 20 charges or 360 hours of operation	(a) Grease fan and intermediate axle bearings. (b) Clean and check thermograph operation. (c) Generally check kiln structure and make any necessary repairs.
Every year or 60 charges or 1000 hours of operation	(a) remove radiator tubes and chimney scrape clean and check for burning through. Replace with new if necessary. (b) Check and repair (if necessary) regulator controls

Notes on operation of Thermograph

The thermograph must be maintained properly to ensure accurate readings. If the kiln appears to be working incorrectly as determined from the thermograph trace, make sure first that it is not the thermograph itself which is at fault. The following are the most important aspects concerning the operation of the instrument:

1. Temperature range: a normal laboratory thermograph has a range of 0 - 50°C. Thus for use in the kiln, with a temperature up to 55°C, the thermograph should be set to read 10 - 15°C lower than the actual temperature. The trace should not be allowed to mark very close to the upper limit of the graph paper, since it will not give an accurate reading, and any extremes will be cut off. Remember to note the difference between actual and recorded temperatures on the instrument.

2. To adjust the thermograph, compare with a thermometer after both have had time to reach ambient temperature, then adjust the thermograph by twisting the red knurled wheel, continually tapping the drum to ensure that the pointer arm does not stick and give a false reading. The thermograph may be checked while in use by inserting a thermometer in the hole at one side of the window in the fan access door.

3. If the trace is not smooth or appears to stick at a fixed temperature, check for an obstruction preventing free movement of the pointer, and also the pressure of the pen against the paper. The latter should be just enough to keep the pen against the paper and no more, otherwise the pen will tend to stick when moving up or down. Adjust the pressure by turning the knurled wheel at the base of the pointer.

4. If the ink flow is poor, check supply and replenish if necessary. It may be necessary occasionally to clean out the reservoir, and ensure that the hairline gap between the two halves of the nib is clear. Adjust the clearance if necessary.

5. If the drum does not turn, check if spring is wound. Do not overwind as the spring may break. If the spring is Ok, check that gears on the drum base are not too loose on their shafts, and hence slipping. Tighten if necessary by removing the gear and closing the split hub using pliers.

6. To economise on the use of graph paper, the paper can be used up side down and back to front to record the trace, thus lasting 4 times longer than normal. To mark the limits at the correct level, refer to another graph paper correctly orientated. The limits are most conveniently marked in red ink, but do not colour the whole area within the lines as this may alter the absorbing characteristics of the paper. For this reason, do not use homemade graphs as the paper may be too absorbent or fibrous.

7. Every so often, clean the whole instrument with a soft bristled brush, and a lint free cloth damped in alcohol. Check adjustment after cleaning.

FAULT GUIDE

The following is a list of some possible faults and their causes.

Fault	Possible causes
1. Kiln does not heat, or only slowly	(a) Radiator blocked or dirty (b) Radiator control stuck or broken shut (c) Insufficient fuel (d) Fans not operating (e) Exit partition louvres closed(*) (f) Cold day and/or air intake /exhaust flap open too much (g) Thermograph broken or stuck. (In this case, BEWARE!! the kiln may be too hot!)
2. Kiln does not cool.	(a) Regulator blocked (above radiator control flap) (b) Radiator control stuck or broken open (c) Very hot day (if solar preheater used) (d) Thermograph broken or stuck.
3. Smoke inside kiln	(a) FIRE!!!! inside kiln - see EMERGENCY instructions. (b) Radiator access panel left open (c) Leak at radiator tube joints (d) Radiator tube burnt out
4. Smoke issues from front of furnace	(a) Chimney damper control closed too much. (b) When radiator control open - radiator blocked. (c) When radiator control shut - regulator blocked above radiator control flap. (d) When radiator control open or shut regulator or chimney blocked. (e) Too much fuel
5. Fans do not turn or slowly (motor OK)	(a) Slipping fan belts (too slack or oily) (b) Loose pulley (c) Loose fan on shaft (d) Fan stuck - bearings dropped and blade stuck against partition
6. Fan motor does not function	(a) No electricity (Note: leave switch off until power restored, to avoid accidents) (b) Fuse burnt (Note: check why) (c) Loose connections (d) Motor jammed or burnt out.
7. Uniformly poor opening/drying	(a) Insufficient airflow - check fans and exit partition louvres (*) (b) Insufficient heat - regime OK? (c) Kiln RH% too high - v, humid day? (d) Charge with high mc%, immature, or insufficiently precured.
8. Non-uniform opening/drying	(a) Insufficient airflow - check fans and exit partition louvres (*) (b) Load not uniform in quality.
9. Opening/drying better above than below	(a) Insufficient airflow - check fans and exit partition louvres
10. Opening/drying better near door than away	(a) Inner fan not working (see 5)
11. Noise or vibration in motor, drive, or Fans	(a) Loose motor, intermediate shaft, or fan shaft mountings (b) Worn motor, intermediate shaft, or fan shaft bearings. (c) Fan blades loose (d) Fan partition joints loose

(*) Check also air entry/exhaust flaps. If separated from each other, intake flap will fall open. If exhaust flap is shut, no air circulation will be possible.

The drying regime is defined by: (i) mean kiln temperature(s), (ii) temperature limits (iii) time and (iv) Relative Humidity of kiln air.

Temperature will be either constant, or at two levels, being increased later in the drying period when the cones (or other fruit) are sufficiently dry so as to withstand the higher temperature.

The temperature limits chosen depend on the precision required. Generally +/- 2°C is sufficiently precise, though greater precision is sometimes required for experimental work.

The time will depend on the initial mc% of the load, and the rate of drying (itself dependent on temp., air RH% etc.)

The RH% of the kiln air depends on ambient air temp. and RH%, kiln temp. and load mc%. The RH% cannot be controlled directly, but in general should be kept as low as possible. The RH% will be lowest for a given kiln temp. with the air intake/exhaust flap full open (single pass), and will rise with increasing recirculation of the kiln air. A balance has to be made between the amount of recirculation, and economy of fuel and use of heated air. Insufficient recirculation wastes heated air and requires heavy fuel consumption to get the temperature increase required.

A typical drying period can be divided into 3 main phases: (i) Heat up phase, (ii) controlled temperature phase, (iii) cooling phase.

During the heat up period (normally about 1 hour to achieve 40°C), the air intake/exhaust flap can be shut (complete recirculation) so as to heat kiln and contents more rapidly. When the operating temperature has been reached, the flap should be opened by the required amount. Thereafter, during the controlled temperature phase, temperature will be maintained as described in the operating instructions.

After running for 8 hours or so, the kiln will have stored a considerable amount of heat in the walls, floor, and load. If an operator is unavailable to continue stoking, further drying can be carried out using this stored heat by leaving the fans running, shutting the air intake/exhaust flap (complete recirculation), and leaving the radiator and chimney controls open (take care that all fuel is used up). About 4 - 6 hours of useful drying can be accomplished during this cooling phase.

Note that when the fans are switched off, almost no drying occurs.

The kiln is most efficient if operated continually, day and night, omitting the cooling down and heat up phases, stopping whenever necessary to carry out maintenance.

If the charge cannot be processed immediately (eg at night), leave in the kiln with all doors shut and fans off, or else remove charge (if another is to be loaded) and cover trays with a tarpaulin to retain warmth and avoid reabsorbtion of moisture.

SUGGESTED REGIMES.

Pinus oocarpa (mc% cones = 20% approx, average ambient temp. and RH%)

1. Continuous operation.	(a) Air intake/exhaust flap open 10 cm. 12 - 18 hours at 50°C
2. Daily operation. (operator available for 11 hours only)	(a) Heat-up phase: air intake/exhaust closed - approx 1 hour.
	(b) Constant temp. phase: air/intake /exhaust flap open 10 cm. 10 hours at 50°C.
	(c) Cool-down phase: air intake/exhaust flaps shut. 6 hours 50°- 30°C (approx.)
	(d) Storage period overnight. Fans off, all doors shut.

Pinus caribaea (mc% cones = 25 - 30%, precured 7 - 10 days, average rainy season ambient temp. and RH%)

1. Continuous operation	(a) Air/intake/exhaust flap open 14 cm. 4 hours at 40°C,10 - 14 hours at 45°C
2. Daily operation (operator available for 11 hours only)	(a) Heat-up phase: air intake/exhaust flaps shut - approx 1 hour
	(b) Constant temp. phase: air intake/ exhaust flaps open 14 cm. 46 hours at 40°C 64 hours at 45°C
	(c) Cool-down phase: air intake/exhaust flaps shut 6 hours 45°C - 35°C (approx)
	(d) Storage period overnight. Fans off, all doors shut.

CONSTRUCTION NOTES

General

The dimensions of the kiln are generally not critical, and some variation is allowable (e.g. trays, fans, radiator), such that precise measurement from the plans is unnecessary. However, it is important to ensure that parts that have to register with other parts are given the right clearance or fit (eg. trays into kiln chamber, trays against partitions, fans in fan aperture, radiator onto regulator, pulleys on axles etc..). Therefore take measurements from the plans with reference to the construction as a whole; the materials available; and the dimensions of the parts already made. Ensure that well seasoned wood is used throughout the construction.

Trays

The trays and platforms should be constructed first, since the final overall size of the stacks will determine the exact dimensions of the kiln chamber and partitions. Use properly seasoned wood. The minimum number of trays required for efficient running of the kiln is calculated as follows:

No. of trays required to fill kiln multiplied by:
No. of days to precure cones (if trays used) multiplied by:
No. of loads processed per day.

Eg. if the kiln takes 64 trays; cones require 6 days precuring; and 1.5 loads processed per day, total trays required will be 64 x 6 x 1.5 = 576.

Building

The main building should be constructed next of whatever material is chosen, making sure that the apertures for the air exhaust and intake flaps, rear access hatch and flue tubes are correctly positioned. Fit the ceiling and roof (if required) once the walls are complete. Fit exhaust and intake flaps.

Partitions

The partitions should be made outside the kiln, ensuring that they fit the overall kiln and tray dimensions. Fit into the building by screwing to far wall and floor, and finally fix false ceiling and ducting. Allow sufficient clearance between partitions B and C so that trays do not jam when wheeled in (about 2.5 cm total in the prototype). Screw and glue partitions together to avoid warping.

Doors

The main doors and fan access door are fixed in position by screwing to the free ends of the partitions, with intervening spaces being filled with plywood or galvanised iron. All doors and flaps should be sealed with gaskets made from rubber strip (old car inner tubes) stapled to the frames.

Fans

Ensure that the fans are made as accurately as possible so as to minimise vibration. Final static balancing of the fans should be carried out with the fan fixed to a freely revolving shaft, and moving the blades in and out of the U-clamps until the fan will rest in any position without a tendency to rotate. At the same time, the angle of attack can be adjusted so as to be uniform. Once the blades are correctly positioned, it is important to fit a safety screw, and ensure that bolts on fans and axles are checked and tightened frequently during the first few months of operation, since wood shrinkage will tend to loosen the joints. If a loose blade flies off, it can do considerable damage!*

Fan drive

If a small diesel or gasoline engine is used, locate this outside the far wall and connect to the innermost fan. This will keep noise and fumes away from the operator. Test run the whole drive system making frequent checks of belt tightness and security of fixing bolts. Fans are designed for low revolutions (250 r.p.m.). Do not try to run them too fast because of the excessive vibration and stresses that will be produced.

Furnace

The sides of the furnace are built first. The reinforced concrete slab top should be cast separately and then lifted and placed on top. Cracks will develop in this slab when heated, but if properly reinforced it will not break up. The fit of the iron doors is not critical, but the greater the air seal, the better will be the control over combustion. The doors may buckle somewhat, but if made only just larger than the aperture, buckling will be minimised. The grate can be easily cast in a small foundry.

Regulator

Make this carefully and ensure that the flaps have sufficient clearance and do not jam. The whole unit is easily welded from flat steel plates which should be 6 mm thick at least.

Radiator

The fan end of the radiator tubes must be allowed to slide in and out of the U-piece to avoid buckling due to expansion. Try to make the sliding joints as accurate as possible to minimise flue gas leaks.

Building the kiln is largely a matter of commonsense once the principles are grasped, and there is wide scope for modifying the design to suit local conditions. If in doubt about a particular alteration in design or construction consult an engineer or write to the author at the address given at the beginning of the paper.

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*Note: Fans are shown unguarded in figures 1, 7, 8 and the frontispiece. They should be guarded and this can be done by fitting a wire mesh guard to the tray rack side of the fan.