Technology Packages:

Solar, Biomass and Hybrid Dryers

Editors:

S. Kumar

S. C. Bhattacharya

Contributors:

Arnold R. Elepaño

Rowaldo R. del Mundo

Mohan Bikram Gewali

Phoeurng Sackona

Technology Packages:
Solar, Biomass and Hybrid Dryers

Editors:

S. Kumar
S. C. Bhattacharya

Contributors:

Arnold R. Elepaño
Rowaldo R. del Mundo
Mohan Bikram Gewali
Phoeurng Sackona

Based on the activities carried out under

RENEWABLE ENERGY TECHNOLOGIES IN ASIA:
A REGIONAL RESEARCH AND DISSEMINATION PROGRAMME

Funded by

Sida

Swedish International Development Co-operation Agency

Co-ordinated by

ASIAN INSTITUTE OF TECHNOLOGY 1959

Asian Institute of Technology

Technology Packages: Solar, Biomass and Hybrid Dryers

PUBLISHED BY

Regional Energy Resources Information Center (RERIC)
Asian Institute of Technology
P.O. Box 4, Klong Luang
Pathumthani 12120
Thailand
E-mail: enreric@ait.ac.th
Website: http://www.serd.ait.ac.th/reric/

ISBN: 974-8202-968

Printed in Thailand

DISCLAIMER

Neither the Swedish International Development Cooperation Agency (Sida) nor the Asian Institute of Technology (AIT) makes any warranty, expressed or implied, or assumes any legal liability for the accuracy or completeness of any information herein provided. References herein to any apparatus, product, trademark or manufacturer does not constitute or imply its endorsement, recommendation or favouring by Sida or AIT.

Foreword

Economic growth, industrialization and growing population in the developing countries of Asia contribute to a rapidly growing demand for energy in the region while global environmental concerns call for limiting use of fossil fuels. Renewable Energy Technologies (RETs) present a viable option of meeting the growing energy demand, especially in remote and rural areas. However, before full commercialization of RETs can be achieved, many barriers need to be overcome. Apart from adaptive technological improvements, this also calls for appropriate financial mechanisms, institutional/research capacity enhancement and public awareness through demonstration and dissemination. The Governments of Asian countries have a key role to play in promotion of RETs through appropriate policy interventions. To address these issues 'Renewable Energy Technologies in Asia: A Regional Research and Dissemination Programme' was launched in 1997 by the Swedish International Development Cooperation Agency (Sida) and the Asian Institute of Technology (AIT). The programme involved thirteen institutes from Bangladesh, Cambodia, Nepal, Lao PDR, Philippines and Vietnam.

The programme activities carried out in the thirteen participating institutes and at AIT included adaptive research, demonstration of RETs systems, dissemination of research outcomes to the stakeholders and capacity building. The wide range of activities and achievements of the RETs in Asia programme have been presented in six booklets:

1. Technology Packages: Solar, Biomass and Hybrid Dryers
2. Technology Packages: Screw-press Briquetting Machines and Briquette-fired Stoves
3. Technology Packages: Low-Cost PV System Components
4. Demonstration and Monitoring of PV Systems: Lessons Learned
5. PV System Components: Technology Fact Sheets
6. Renewable Energy Technology Promotion in Asia: Case Studies from six countries

The information presented in the above booklets is expected to be useful to a number of stakeholder groups, including those who are involved in renewable energy development projects in the Asian region, the business community, policy personnel, NGOs, etc.

Dr. Gity Behravan

June 2005 — Senior Research Advisor, Sida

Preface

It is increasingly becoming evident that current pattern of rising conventional energy consumption cannot be sustained in the future due to two reasons: the environmental consequences of heavy dependence on fossil fuels, particularly climate change, and the depletion of fossil fuels. Therefore, at present, a near consensus appears to be emerging that renewable energy technologies need to be promoted if global energy supplies are to be placed on an environmentally sustainable path.

Despite the efforts of various government institutions, universities, NGOs and international development organizations, renewable energy technologies are yet to make a substantial contribution towards betterment of the quality of life in the developing countries. To find a wider acceptance, it is very important to make sure that renewable energy solutions are accessible, affordable and appropriate. Research and development institutes in developing countries have a vital role to play in the development, local adaptation and promotion of renewable energy technologies. These institutes have much to gain through regional networking with similar institutes in other countries by sharing experience and carrying out joint coordinated research.

In this background, the Swedish International Development Cooperation Agency (Sida) sponsored a regional programme entitled "Renewable Energy Technologies in Asia: A Regional Research and Dissemination Programme (RETs in Asia)". The programme, executed during 1997-2004, was coordinated by the Asian Institute of Technology (AIT) and involved thirteen National Research Institutes (NRIs) from six Asian countries: Bangladesh, Cambodia, Lao PDR, Nepal, Philippines and Vietnam. Three technologies/applications were identified for research, promotion and dissemination: solar photovoltaics, renewable energy based drying and biomass briquetting/briquette-fired stoves.

Six booklets have been prepared to disseminate the findings of the RETs in Asia programme. This document presents technical information on the different renewable energy based drying systems developed at AIT and in the three participating countries: Cambodia, Nepal and Philippines. The information is expected to be useful to those who are involved in drying related development projects in the Asian region, the business community as well as NGOs/research institutes.

We are grateful to the Swedish International Development Cooperation Agency (Sida) for providing financial assistance for all the activities carried out within the programme. We are also thankful to Dr. Gity Behravan of Sida for her continuous support and guidance over the implementation period.

Prof. S. Kumar

June 2005

RETs in Asia Coordinator

RETs in Asia Project Team

Swedish International Development Cooperation Agency (Sida)

Dr. Gity Behravan – Senior Research Advisor

Principal Investigators

Prof. S.C. Bhattacharya – Energy Field of Study, AIT (until December 2004)
Prof. S. Kumar – Energy Field of Study, AIT

National Research Institute (NRI) Team Leaders

Bangladesh

Mr. Dipal C. Barua
Managing Director, Grameen Shakti (GS)
Grameen Bank Bhaban, Mirpur - 2, Dhaka - 1216, Bangladesh.
Tel: +88 02 9004081; Fax: +88 02 803559; E-mail: g_shakti@denbd.com

Prof. Muhammad Ibrahim
Executive Director, Centre for Mass Education in Science (CMES)
House #828, Road #19, Dhanmondi Residential Area, Dhaka - 1209, Bangladesh.
Tel: +88 02 811898; Fax: +88 02 803559; E-mail: cmes@citechco.net

Prof. Md. Nawsher Ali Moral
Mechanical Engineering Department, Khulna University of Engineering and Technology (KUET) Khulna 9203, Bangladesh.
Tel: +88 041 774900; Fax: +88 041 774403; E-mail: nali@bttb.net.bd

Cambodia

Dr. Sat Samy
Under Secretary, Ministry of Industry, Mines & Energy (MIME)
No. 47, Preah Norodom Blvd. Phnom Penh, Cambodia.
Tel: +855-23-427851; Fax: +855-23-990602; E-mail: mimedet@forum.org.kh

Dr. Phoeurng Sackona
Director, Cambodia Institute of Technology (ITC)
Pochentong Boulevard, P.O. Box 86, Phnom Penh, Cambodia.
Tel: +855 23 880 370; Fax: +855 23 880 369; E-mail: sackonap@bigpond.com.kh

Lao PDR

Dr. Phouvong Sayalath
Technology Research Institute, Science Technology and Environment Agency (STEA)
P.O Box 2279, Vientiane, Lao PDR.
Tel: +856 21 218711; Fax: +856 21 213472; E-mail: tri@steno.gov.la

Nepal

Er. Rishi K. B. Shah
Vice President, Centre for Renewable Energy (CRE)
P.O. Box 589, Ga-2/717 Bag Bazaar, Kathmandu, Nepal.
Tel: +977 1 248852; Fax: +977 1 226976; E-mail: cre@ccslnp.com

Prof. Mohan Bikram Gewali
Executive Director, Research Centre for Applied Science and Technology (RECAST)
Tribhuvan University
P. O. Box 1030, Kirtipur, Kathmandu, Nepal.
Tel: +977 1 330348; Fax: +977 1 331303; E-mail: turecast@mail.com.np

Mr. Gyani Ratna Shakya
Director, Technology Division, Royal Nepal Academy of Science & Technology (RONAST)
P.O. Box 3323, Khumaltar, Patan, Nepal.
Tel: +977-1-547719; Fax: +977 1 490190 / 547713; Email: grshakya@hotmail.com

Philippines

Prof. Rowaldo R. del Mundo
Head of Solar Laboratory, University of the Philippines Diliman (UPD)
Quezon City, Philippines 1101.
Tel: +632 434 3661; Fax: +632 4343660; E-mail: rmundo@info.com.ph

Dr. Arnold R. Elepaño
Associate Professor, College of Engineering and Agro-Industrial Technology
Institute of Agricultural Engineering, Division of Agricultural & Bio-Process Engineering
University of the Philippines Los Baños (UPLB), College, Laguna 4031, Philippines.
Tel: +63 49 536 2650; Fax: +63 49 536 3291; Email: retsas@laguna.net

Vietnam

Dr. Pham Khanh Toan
Director, Institute of Energy (IE)
Khuong Thuong - Dong Da, Hanoi, SR Vietnam.
Tel: +844 8522453; Fax: +844 8523311; E-mail: ret@fpt.vn

Mr. Trinh Quang Dung
Director, Solar Laboratory (SolarLab)
01 Mac Dinh Chi St., 1 District Ho Chi Minh City, SR Vietnam.
Tel: +84 8 8222 028, Fax: +84 8 8295 905; Email: t-qdung@hcm.fpt.vn

Research Staff at AIT

Mr. Mathias Augustus Leon – Energy Field of Study, AIT. Email: augustusleon@gmail.com

Mr. Md. Anisuzzaman – Energy Field of Study, AIT. Email: aniszm@yahoo.com

Contents

Introduction

In 1997, the Swedish International Development Cooperation Agency (Sida) launched a programme entitled “Renewable Energy Technologies in Asia: a Regional Research and Dissemination Programme (RETs in Asia)”. The objective of the programme, which was coordinated by the Asian Institute of Technology (AIT), was to promote a few selected mature / nearly mature renewable energy technologies in six Asian countries, i.e., Bangladesh, Cambodia, Lao PDR, Nepal, Philippines and Vietnam. Thirteen national research institutes (NRIs) from the six countries were involved in the regional programme. The activities of the programme involved adaptive research, development of technology packages and their demonstration, capacity building of different stakeholder groups, and dissemination.

Three renewable energy technologies were selected for promotion within the programme: photovoltaics, renewable energy-based drying, and biomass briquetting / briquette-fired stoves. One of the major objectives of the RETs in Asia programme was to develop appropriate 'packages' on the selected technologies, highlighting the outcome of adaptive research and development efforts. These packages are being disseminated to interested entrepreneurs and other stakeholders in the participating countries and the region as a whole. This booklet documents the technology packages developed on renewable energy-based drying, both by AIT and by the participating institutions.

The technology packages developed by RECAST (Nepal) include a solar box dryer, a solar cabinet dryer, a solar tunnel dryer, and a solar-biomass hybrid cabinet dryer. ITC, Cambodia developed a solar box dryer and two models of chimney type cabinet dryers. UPLB (Philippines) developed two models of cabinet dryers of different capacities, while UPD (Philippines) developed a transpired collector solar-biomass hybrid cabinet dryer.

Three types of dryers were developed at AIT (Thailand): a solar-biomass hybrid tunnel dryer, which was designed for the drying requirements of small and medium farmers; a direct-solar box dryer, developed for small farmers and household use; and a solar-biomass hybrid cabinet dryer, which uses a gasifier stove as an additional heat source. The following sections describe the packages developed.

These packages are described in greater detail (design drawings, construction manuals, photographs etc.) in a CD. The CD also includes detailed information on the other renewable energy technologies promoted under the RETs in Asia programme: photovoltaics and biomass briquetting. Information on the project activities are described under the following sub headings: adaptive research and development, technology packages, demonstration / case studies, trainings / manuals, publications, and seminars / workshops / conferences. The CD can be obtained from the coordinator of RETs in Asia project at the address given in the inside back cover.

Chapter 1

PACKAGES DEVELOPED AT AIT, Thailand

Package 1: Direct Solar Box Dryer

A direct-solar box-type dryer has been developed at AIT after optimizing the design parameters through a detailed study. The dryer, which operates on the natural draft principle, has two trays kept inside an insulated box. The trays are made of aluminum angle frames and stainless steel wire mesh. A cover glazing, hinged at one side to the box, is fixed at the top. The glazing can be opened for loading and unloading of the dryer. The dryer is fixed on an inclined stand, facing the south. The main parameters which determine the drying air temperature are the distances of the cover glass and the dryer bottom surface from the tray surface. These parameters have been optimized, to adjust airflow both above and below the trays to enhance the air contact with the product. Figure 1.1 shows the assembled drier. The physical parameters of the dryer are presented in Table 1.1.

Products to be dried are spread on a thin layer over the two trays kept inside the box. During operation, the hot and humid air escapes through an opening at the top, while fresh ambient air enters through a bottom opening.

Figure 1.1: A fully assembled direct-solar box dryer

Design details

The box dryer consists of a rectangular box made of galvanized iron (GI) sheet, with an open top. The box was insulated at the outside with glass wool, and clad with GI sheet. An aluminum frame around a 3 mm thick window glass cover was hinged to the box at the left edge. This facilitates opening and closing of the cover glass for access into the box. Figures 1.2 and 1.3 illustrate the dimensional details of the dryer.

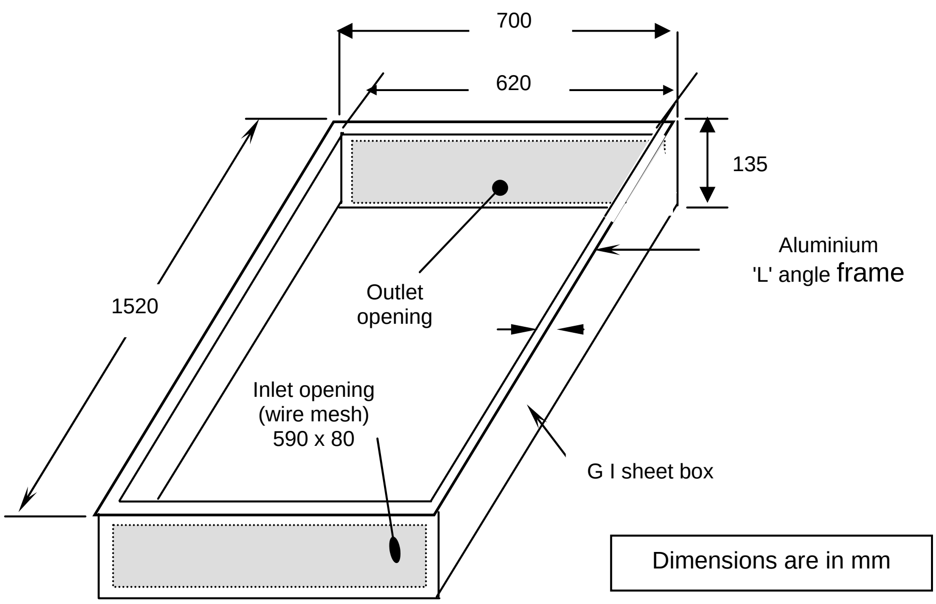
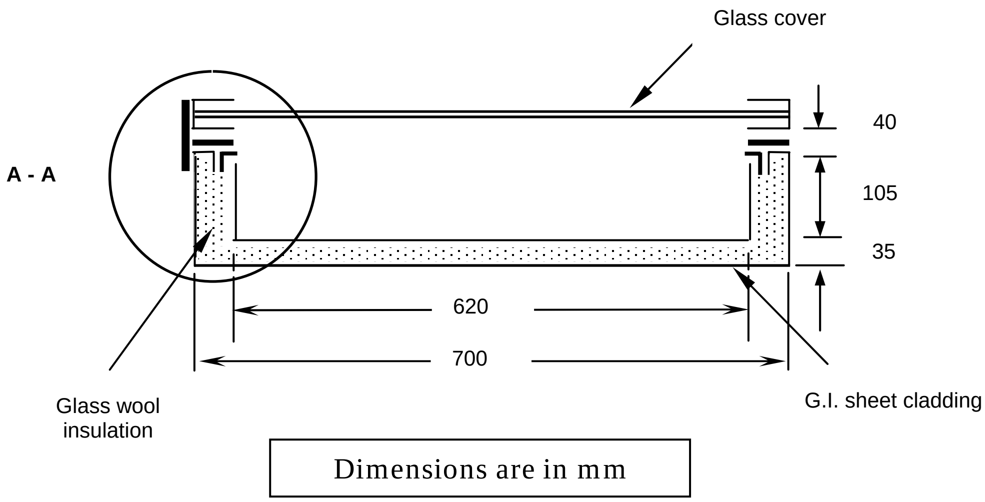


Figure 1.2: Dimensional details of the direct-solar box dryer

Table 1.1: Technical specifications of the direct-solar box dryer

SI. No.	Parameter	Specifications
1	Type of dryer	Direct solar
2	Overall size - length x width	152 cm x 70.5 cm
3	Height	15.5 cm
4	Aperture area	0.91 cm^2
5	Loading (tray) area	0.84 cm^2
6	Air inlet / outlet areas	472 cm^2 each (59 cm x 8 cm)
7	Box material	GI sheet, 22 SWG
8	Tray materials	Aluminum frame; SS wire mesh
9	Glazing	3 mm window glass
10	Gap: Tray surface-Cover glass	10 cm
11	Gap: Tray surface - Dryer bottom surface	2.5 cm



Section A - A

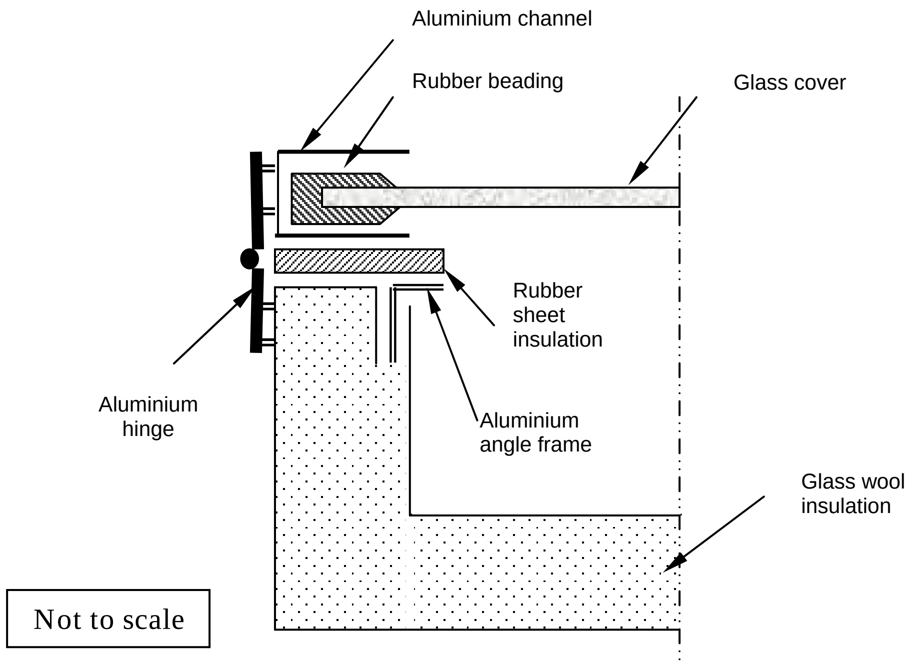


Figure 1.3: Sectional views of the box dryer

The box dryer was aimed at rural households, and tested with a number of fruits and vegetables, including apple, banana, chilly, mushroom and radish. The dryer could provide an average drying air temperature of 50-55°C inside the drying chamber. Drying is much faster compared to open sun drying, and the dried products were found to be of good quality.

Package 2: Solar-Biomass Hybrid Cabinet Dryer

Small-scale drying based on electricity, coal, LPG and other fossil fuels is normally expensive. Moreover, combustion of fossil fuels emits greenhouse and other gases. Solar drying is an attractive option to solve some of these problems. However, an inherent problem of solar drying is that it depends entirely on the weather and is not possible to use during night-time.

Biomass is locally available in rural areas of developing countries and is often the cheapest source of energy. In addition, biomass fuels can provide an uninterrupted supply of thermal energy needed for continuous operation of dryers. Hybrid drying powered by biomass and solar energy is a potentially important option for small-scale operations since it combines the advantages of drying systems operated by solar energy alone and those operated by biomass alone. During sunny weather, the dryer is operated in the solar mode which reduces the need for biomass fuels and associated costs. Use of biomass fuels, however, enables a continuous day and night operation even during cloudy or rainy weather.

A hybrid cabinet dryer with an automatic temperature control mechanism has been developed at AIT for drying agricultural products. The hybrid pairs a domestic gasifier stove (DGS), developed at AIT, and a flat plate solar air heater to supply hot air for drying products inside a cabinet. The technical specifications of the dryer are presented in Table 2.1.

Table 2.1: Technical specifications of solar-biomass hybrid cabinet dryer

SI. No.	Parameter	Specifications
1.	Solar Collector type	Flat plate air-heating solar collector
2.	Solar Collector size	2m x 2m
3.	Drying chamber dimensions	2m (length) x 2m (breadth) x 1.95m (height)
4.	Drying chamber construction	Bricks and mortar
5.	No. of trays	16 nos.
6.	Total tray area	14 m^2
7.	No. of doors for loading / unloading	4 nos., two at each side
8.	Stove type	Natural convection cross-flow gasifier stove
9.	Gasifier stove capacity	4.5 kW (thermal)
10.	Fuel for gasifier stove	Wood chips, wood twigs, briquette pieces
11.	Heat exchanger type	Pipe heat exchanger
12.	Airflow inside the drying chamber	Natural convection, with chimneys
13.	Temperature controller	Thermostat-based, mechanical lever control

The main advantage of using the gasifier stove is that the dryer can be operated continuously for several hours with a steady heat input, with minimum attention. This dryer is constructed of bricks and mortar, and is more efficient than a conventional solar cabinet dryer made of steel or aluminum.

The hot flue gases from the biomass gasifier stove are used to heat the process air inside the drying chamber, using a pipe heat exchanger and an automatic temperature control mechanism that allows the temperature of air inside the drying cabinet to be maintained in the range 55-65°C.

Design Details

Drying Chamber

The drying chamber is 2m x 2m in cross-section and has a height of 1.95m. The foundation is made of 1m deep concrete pile. Figures 2.1, 2.2 and 2.3 illustrate the dryer. The drying chamber has brick walls on all four sides. The doors, as shown in Figure 2.3, were made of two layers of G.I. sheet with fiberglass insulation in between to reduce the heat loss; a narrow transparent area allows viewing of the products from outside during drying (Figure 2.1)

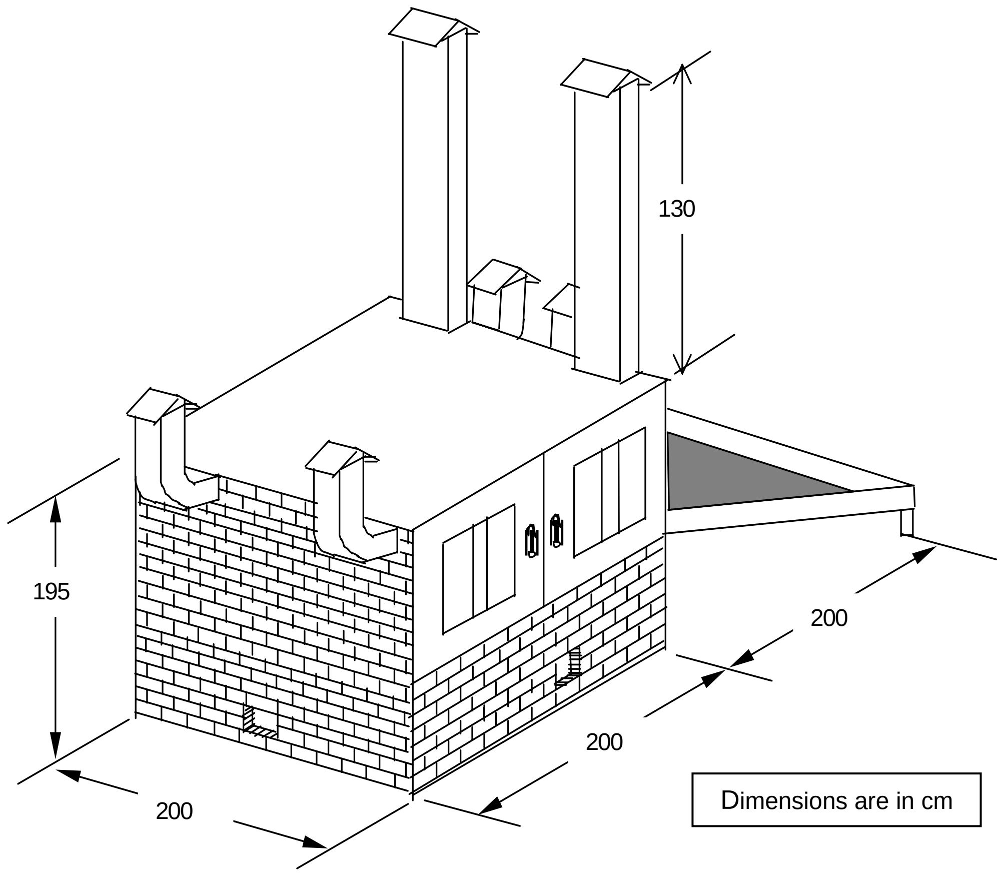


Figure 2.1: Configuration of the drying chamber

Figure 2.2 Solar-biomass hybrid cabinet dryer

Two doors were designed for easy loading and unloading of the products. There are four process air outlets from the drying chamber; the outlet air flow can be adjusted by slide plates to partially close these outlet openings. The product to be dried can be loaded inside the dryer at four levels. Each level has four trays (Figure 2.3).

Figure 2.3: Inside view of the drying chamber

Gasifier Stove

The gasifier-gas burner component of the stove (Figure 2.4) consists of four main parts – fuel chamber, reaction chamber, primary air inlet and combustion chamber; these parts are assembled using bolts and nuts.

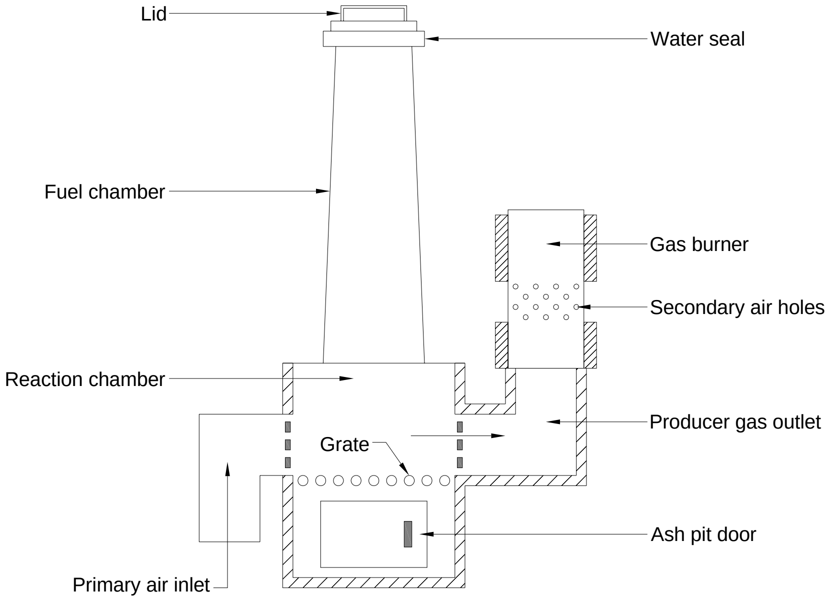


Figure 2.4: Schematic diagram of the domestic gasifier stove DGS2

A photograph of the stove is presented in Figure 2.5. The stove's components are illustrated in the following sections.

Figure 2.5: Fully assembled domestic gasifier stove

An exploded view of the gasifier-gas burner component of the stove is shown in Figure 2.6.

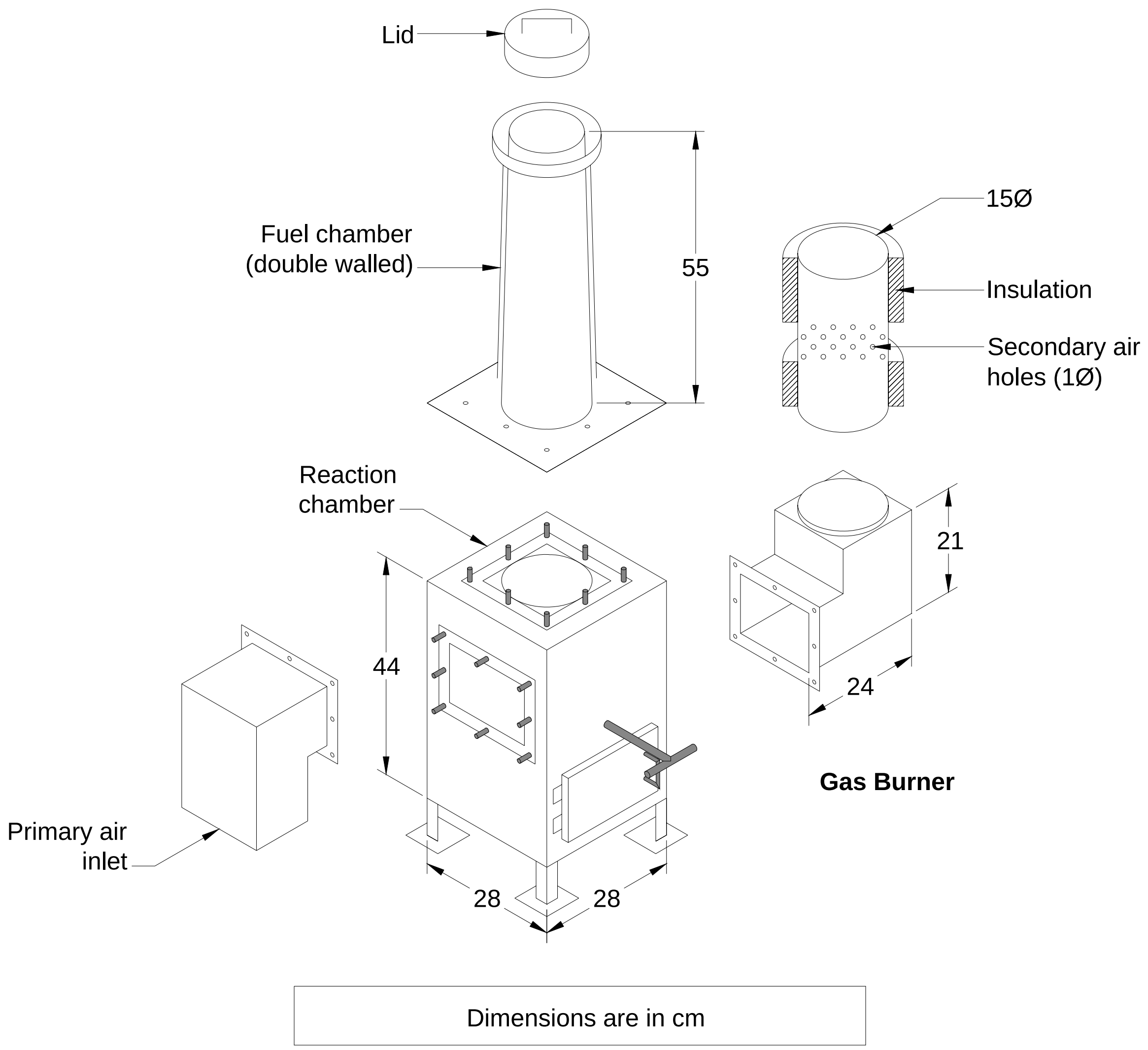


Figure 2.6: Exploded view of the gasifier stove.

Asbestos gaskets are used while connecting the different parts together. To prevent rusting, before and after assembling, the metal parts are painted with a high temperature spray paint (e.g.: No. 1200 HI-TEMP 1200°F Flat Black Spray Paint, of Bosny brand) available in hardware stores.

Reaction chamber: The reaction chamber (Figures 2.7 and 2.8) is the key component of the stove where producer gas is generated. The outside wall of the chamber is made of 2 mm thick mild steel sheet, and fabricated over an L-angle frame of outside dimensions 28cm x 28cm x 44cm. The inside wall is made of a slotted mild steel cylinder; a layer of bricks, cemented together by Castable-13 refractory cement is placed between the two walls for thermal insulation.

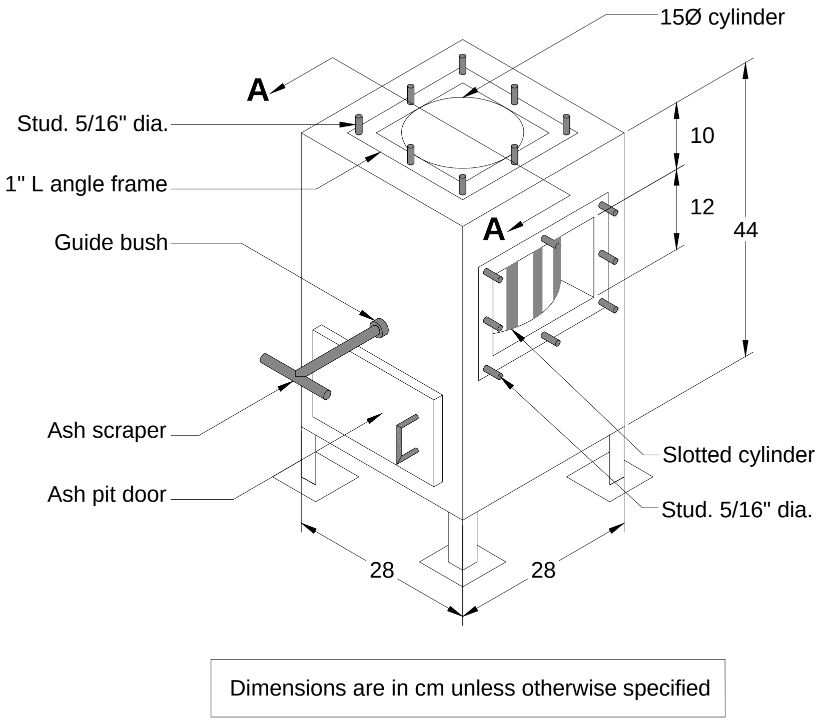


Figure 2.7: Isometric view of the reaction chamber

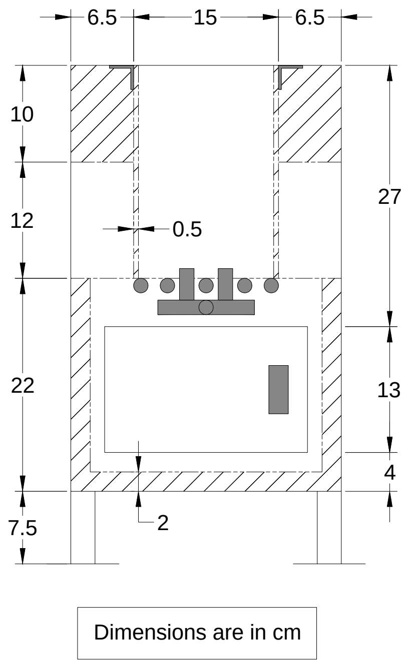


Figure 2.8: Cross-sectional view of reaction chamber

The slotted cylinder, forming the inner wall of the reaction chamber, is of 5 mm thick mild steel sheet, with an open top and a grate welded to its base. The cylinder has slots for air inlet and gas outlet, through which primary air enters into the reaction chamber at one side, and the producer gas exits the reaction chamber at the other side. The slots, six at each side, are provided as illustrated in Figure 2.9.

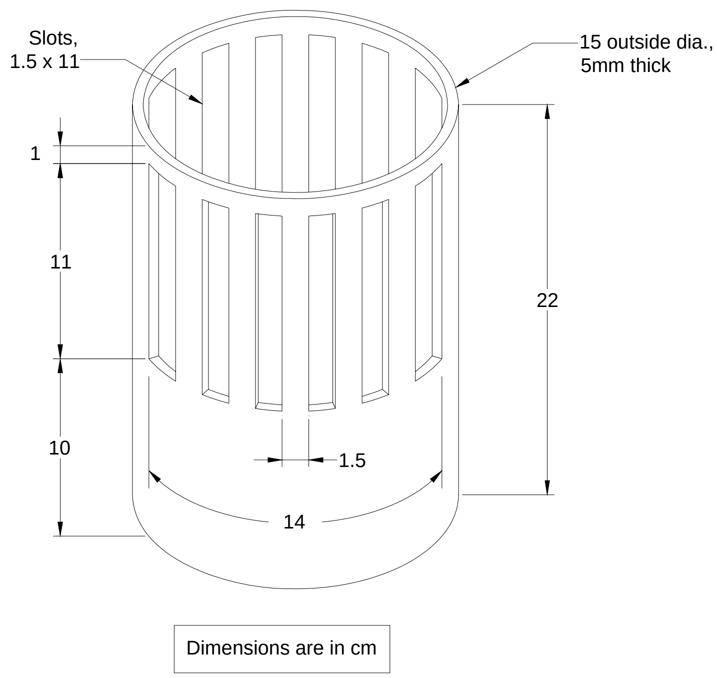


Figure 2.9: Slotted cylinder (shown upside down)

A mild steel grate is welded to the base of the cylinder. The grate (Figure 2.10) is made of round mild steel rods of 12.5 mm diameter, and allows ash to fall through it into the ash pit. An ash scraper (Figure 2.11) is fixed below the grate, to remove ash accumulated inside the reaction chamber. The ash scraper is especially useful while using fuels of high ash content, such as ricehusk briquettes, since accumulated ash could otherwise block the flow of fresh fuel from the fuel chamber into the reaction chamber.

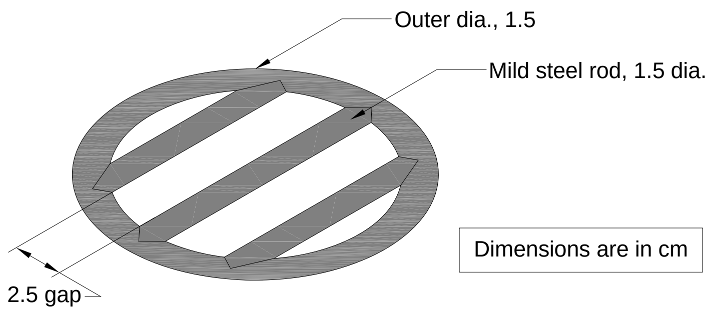


Figure 2.10: Grate (welded at the base of the perforated cylinder)

The ash scraper slides through a cylindrical guide bush, which is welded to the body of the reaction chamber. For easy assembling, the slider rod is connected to the 'fingers' of the scraper by a threaded joint. The ash scraper is operated by sliding it in and out horizontally, generally once in 10-20 minutes, depending on the ash content of the fuel.

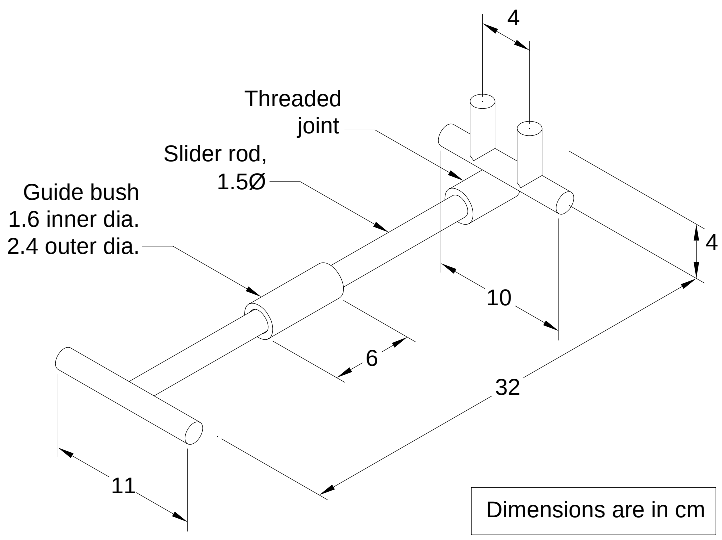


Figure 2.11: Ash scraper (with support bush)

A door is provided below the grate level in the reaction chamber, to access the ash pit. The door, made of 2 mm thick mild steel sheet, is fixed to the reaction chamber body using two hinges. A handle is welded to the door for easy opening and closing. The door is insulated with a refractory cement (Castable 13) layer of 1.5 cm thickness (Figure 2.12).

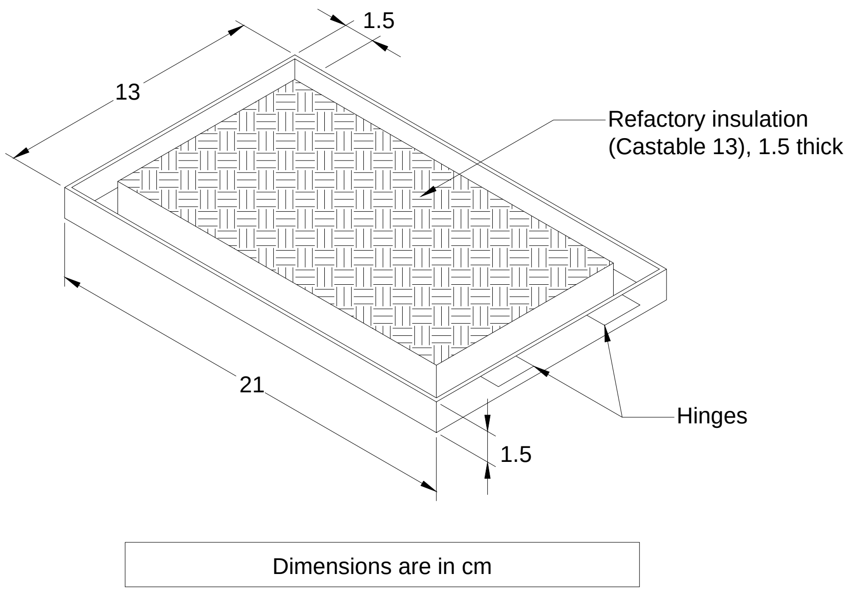


Figure 2.12: Ash pit door (Inside view)

The ash accumulated in the ash pit is periodically removed by opening this door. The door is also used while igniting the stove, by introducing a flame torch from below the grate, which supports the fuel bed inside the reaction chamber.

Fuel chamber: The fuel chamber (Figure 2.13) is made of 2 mm thick mild steel sheet and is located above the reaction chamber. Fuel from the fuel chamber flows into the reaction chamber by gravity. The chamber is designed to be conical in shape, to avoid ‘fuel bridging’ inside the chamber, and to facilitate easy flow of fuel. The top end of the chamber has a water seal and a cup-type lid for easy loading of fuel; the water seal also prevents gas leakage from the joint during operation.

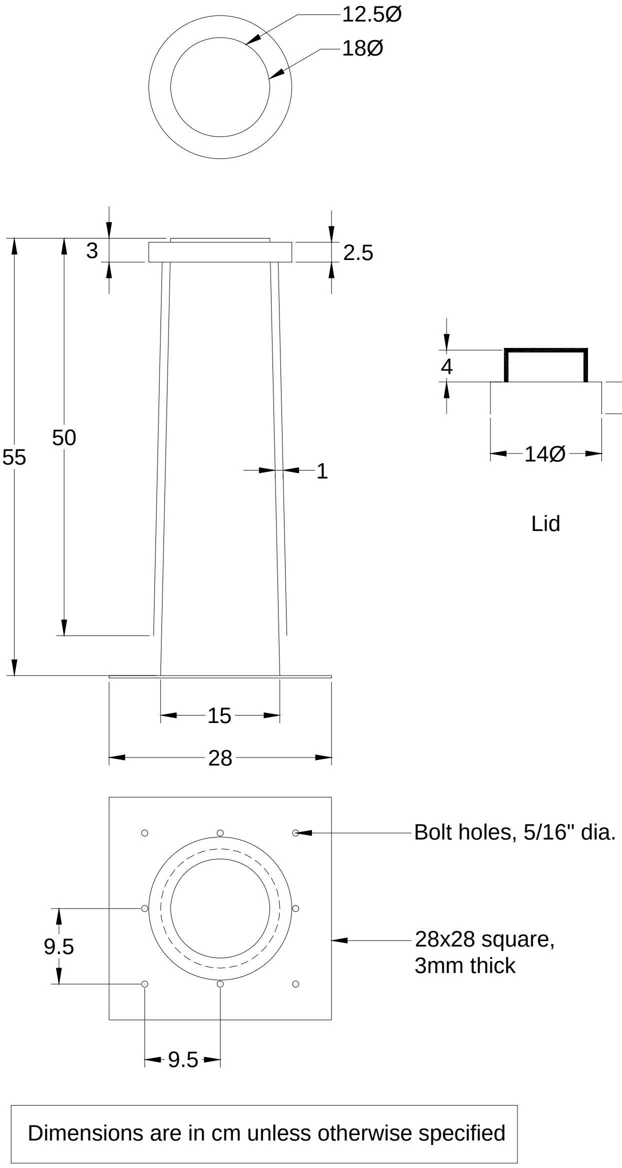


Figure 2.13: Fuel chamber

To protect the stove operator from accidental burns, and to reduce the heat losses further, the outside of the fuel chamber is covered with a mild steel shell, which is welded at the top with the water seal. The fuel chamber has a flange attached at its bottom; this is used for connecting the fuel chamber with the reaction chamber.

Primary air inlet: The primary air inlet (Figure 2.14) is made of 2 mm thick mild steel sheet, and is attached on one side of the reaction chamber. It is provided with a butterfly valve, which can be used to control the gasification rate inside the reaction chamber by controlling the primary air flow.

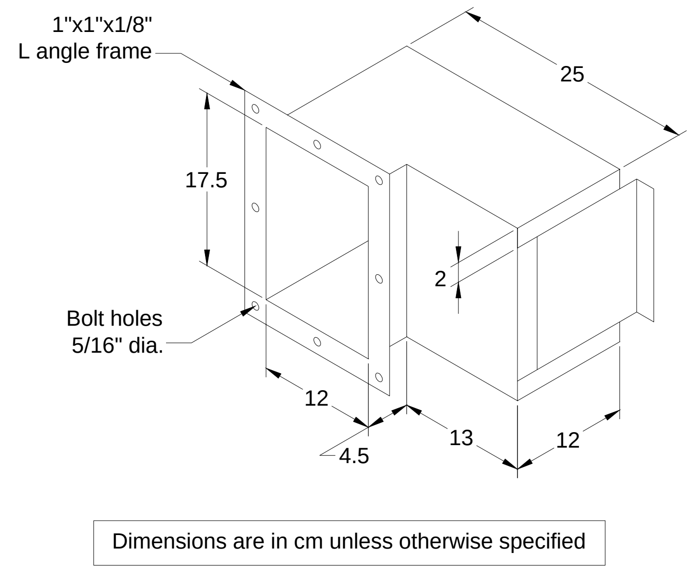


Figure 2.14: Isometric view of primary air inlet manifold

Gas Burner: The gas burner has two parts: the support at the bottom or gas burner base (Figure 2.15) and the burner pipe (Figure 2.16) which is fitted over the base.

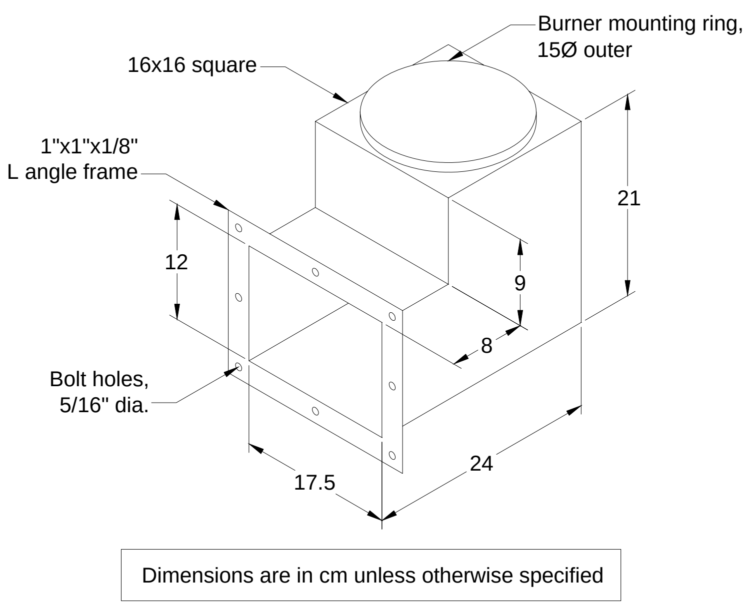
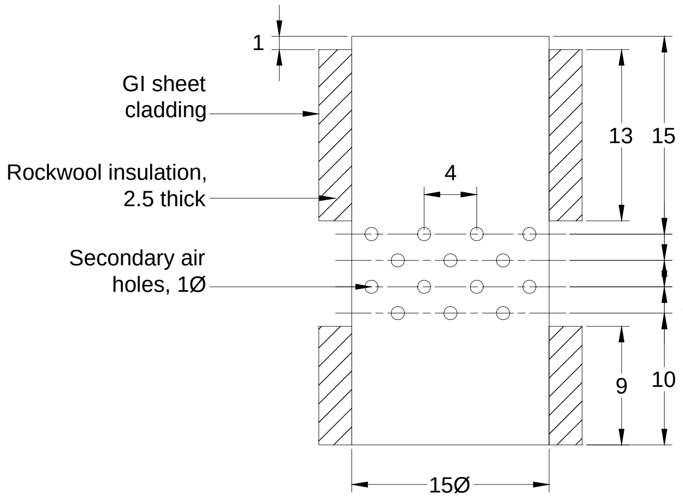


Figure 2.15: Isometric view of gas burner base

The burner pipe has forty-four holes of diameter 10 mm drilled into it in four rows, through which secondary air flows in, for combustion of the producer gas. To reduce heat losses, the surfaces above and below the secondary air holes are insulated with rockwool and clad with 1 mm thick GI sheet.



Dimensions are in cm unless otherwise specified

Figure 2.16: Sectional view of the gas burner

The gas burner base is insulated with a 2 cm layer of refractory cement (Castable 13) on its entire inner surface. The insulation reduces heat loss from the gases as they exit the reaction chamber before their combustion in the gas burner.

Asbestos gaskets are used in the assembly of the individual components together. Three gaskets, of size 28cm x 28cm, 17.5cm x 12cm and 17cm x 20cm (outer dimensions), are used for connecting the fuel chamber, primary air inlet and the gas burner respectively, to the reaction chamber.

Fuel Characteristics: The gasifier stove is reasonably versatile in terms of the types of fuels it can handle. Ricehusk briquettes, wood chips and coconut shells were tested and found to be suitable for use in the gasifier stove.

(i) Ricehusk briquettes (ii) Wood chips (iii) Coconut shells

Figure 2.17: Fuels used in the gasifier stove

Other fuels such as saw dust briquettes and wood twigs can also be used in the stove. The fuel should be sized before loading into the fuel chamber. Figure 2.17 illustrates the types of fuels used in the stove. One inch is the average size of fuel pieces that can be used.

Stove ignition: Fuel is first loaded in the fuel hopper, the lid is closed and the water seal is filled with water. The fuel is then ignited from below the grate using a flame torch through the ash pit door.

About five minutes later, the torch is removed and the ash pit door is closed. The ignition builds up slowly, taking about 20 minutes for the combustible gases (producer gas) to generate at the gas burner side. The gases are then ignited in the gas burner by introducing a flame through the secondary air holes in the burner.

Once the gas is ignited, the flow of gas becomes smooth. The stove can operate continuously for several hours, until the fuel in the fuel chamber is used up. Additional fuel can be loaded through the top of the fuel chamber to extend operation.

Flat Plate Solar Collector

The dimensions of the flat plate solar air heater are 2m x 2m. The cover glazing is 4 mm thick tempered glass. Glass wool insulation is provided below the absorber sheet. The absorber and insulation materials are placed inside a mild steel box, which protects the interior from moisture/rain. The air inlet to the collector is fitted with a fine stainless steel wire mesh. The solar collector is placed facing south at an angle of 15° to the horizontal for absorbing maximum solar radiation during summer.

Heat Exchanger

A heat exchanger transfers heat from the flue gas from the gasifier stove to the drying air entering from the solar collector and bottom air blowers/openings of the drying chamber. The heat exchanger, fitted above the level of the solar collector air outlet, is of cross-flow type with hot flue gas flowing through horizontal pipes and process air flowing up across these pipes.

The central pipe of the heat exchanger (6” diameter) and two side pipes (4” diameter) are fabricated from mild steel sheet. The center pipe and side pipes are connected with eighteen 2” diameter steel pipes.

Temperature Controller

A temperature controller using a thermostat is provided to maintain the temperature of hot air within specified limits. The thermostat controls the primary air supply to the biomass stove. A car radiator thermostat with a working temperature of 76.5°C is used as a temperature controller in the drying system. The thermostat is fixed inside a housing which has eight copper fins, each of size 7cm x 3cm welded to an annular cylinder. This housing has been provided to enhance the heat transfer from the hot air to the sensing element in the thermostat. The thermostat is fixed on the central heat exchanger pipe near the entrance of flue gas from the gasifier stove. The temperature of drying air inside of the dryer can be set to a particular value by adjusting the height of the thermostat expander rod above the heat exchanger pipe.

When the average temperature inside the dryer rises above the desired level, the thermostatic element will extend and push the short arm of a lever; the long arm of the lever pulls a vertical rod to close the butterfly valve at the stove's inlet so that flow of primary air to the gasifier stove will be reduced.

When the airflow to the reaction chamber is reduced, the amount of producer gas generated for combustion is also reduced, so that the temperature in the drying chamber drops. When the temperature drops to a set level, the thermostat will move back to the normal position and the butterfly valve will be opened.

The mechanism of the control system of the thermostat is illustrated in Figure 2.18. A photograph of the thermostat, fixed inside the drying chamber, is presented in Figure 2.19.

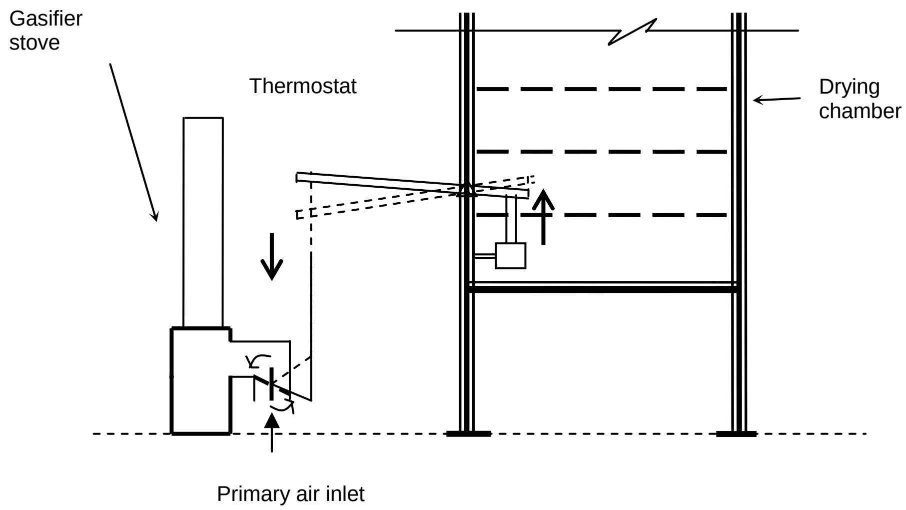


Figure 2.18: Thermostat working principle

Using the temperature controller, the inside temperature of air inside the drying chamber can be maintained in the range of 55-65°C.

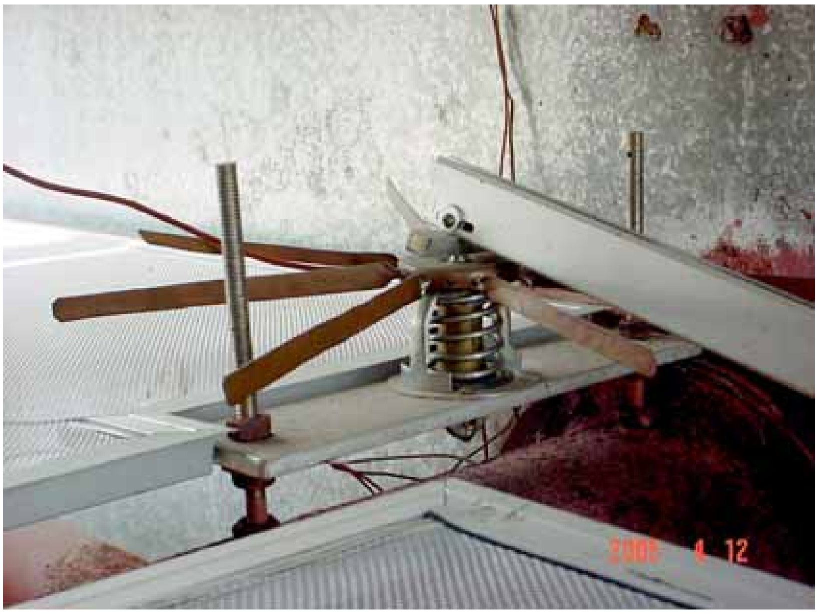


Figure 2.19: Thermostat used in the temperature control mechanism

The completed hybrid solar-biomass cabinet dryer is presented in Figure 2.20. The dryer has been tested with products such as banana, mushroom, chilly and radish, and the performance is found to be good.

Figure 2.20: The solar-biomass hybrid cabinet dryer

Package 3: Solar-Biomass Hybrid Tunnel Dryer

Considering the low land-holding of marginalized rural farmers in developing countries, a solar tunnel dryer has been designed for drying small quantities of agricultural products that are harvested by the farmers in the region.

This dryer is an adaptation of the tunnel dryer developed at the University of Hohenheim, Germany. The prototype described here is suitable for drying 115 kg of fruits (banana) and has been designed and fabricated at AIT.

Design Details

The dryer (Figure 3.1) consists of a flat plate air-heating solar collector, integrated with a drying chamber. A common glazing, provided for both the collector and the drying chamber, forms a tunnel. A biomass stove-heat exchanger assembly is fitted at one end of the tunnel, at the collector side. The biomass stove is used as an alternate heat source for the dryer when solar energy is not available.

The integrated collector-dryer unit rests on footings made of brick and mortar. The exact size of the brick column depends on the size of locally available bricks and may vary from place to place.

Several trays are provided inside the drying chamber, on which the products are loaded in a thin layer. During day time, the dryer is operated as a solar dryer. In cloudy weather conditions or at night, the biomass stove may be used.

Figure 3.1: The solar-biomass hybrid tunnel dryer

The dimensions and other design parameters of the AIT solar-biomass hybrid dryer are presented Table 3.1. Table 3.2 lists the materials used for constructing the dryer.

Table 3.1: Technical specifications of solar-biomass hybrid tunnel dryer

Width	1.8 m
Length (collector)	4.00 m
Length (dryer)	4.25 m
Length (total)	8.25 m
Collector Area	7.2 m^2
Drying area	7.65 m^2
Total number of fans	5
Approx. air flow rate (single fan)	130 m^3/h
Power consumption (single fan)	14 Watts
Top cover	0.2 mm thick UV-treated PE
Bottom insulation	4 cm-two layers of 25mm glass wool

Two GI sheets are riveted together, with glass wool or any material with good thermal insulation properties and a square steel tube sandwiched in-between them, to form a module. The base of the integrated collector-dryer unit is made of such modules. Individual modules are joined together by riveting GI strips placed above and below the adjacent modules; the base is next made to fit inside the side support. The base slides through grooves in the side supports. The side support is made to hold both the base of the collector-dryer unit and its top polythene cover.

The polythene cover rests on the roof supports. Each roof support has a hole drilled in the middle, and is fixed to the side support by riveting. A square pipe is attached to the module by using nuts and bolts on the two ends of the solar dryer. A steel wire that provides extra support for the roof passes through the holes made on the roof supports and is attached to the square pipes using clamps.

Rubber gaskets (curved) are fixed with superglue (or Loctite) to cover all the sharp edges of the side support (top edge) that comes in contact with the polythene cover. The polythene cover is fixed to the side support at one side along the length of the dryer. Plastic clamps (car window washers) are used to press the polythene sheet against the sealed edge of the side support. At the other side, it is rolled on a G.I. pipe of diameter 1 inch. A crank attached to the GI pipe serves to roll the polythene cover further to open the drying chamber while loading and unloading the trays. During normal operation, the polythene sheet covers the whole dryer.

The zinc coating on the GI sheet of the collector base is abraded using sand paper. This surface is then painted with matt black paint.

Table 3.2: Construction materials used for solar-biomass hybrid dryer

S.No	Item Description	Unit	Quantity
1.	Galvanised Iron (GI) sheet, #18, 4'*8'	sheet	3
2.	Galvanised Iron (GI) sheet, #28, 3'*6'	sheet	18
3.	Galvanised Iron (GI) pipe, ϕ = 1"	meter	6
4.	Mild Steel (MS) pipe (square), 3/4"	meter	12
5.	Mild Steel (MS) pipe (square), 1.5"	meter	36
6.	Aluminium 'L' angle, 1"*1", 3 mm thick	meter	24
7.	Aluminium split bar, 1/2"* 1mm thick	meter	24
8.	Aluminium flat bar, 1/2"	meter	6
9.	Aluminium flat bar, 1"	meter	24
10.	Aluminium wire mesh, 1mm sieve	meter	10
11.	Aluminium washers	pcs.	
12.	Aluminium rivets, 1/8"*1/2"	pcs.	1,000
13.	ACSR (Alu. Conductor, Steel Reinforced) wire, 1/4"	meter	12
14.	Super Glue	tube	4
15.	Silicone sealant, 330 ml	tube	1
16.	Glasswool, 1.22m*30.50m*2mm(blanket)	kg	22.3
17.	Electric Fan, 220 V/AC, 14 W	pcs.	5
18.	Car window/door seal	meter	18
19.	Rubber gasket (flat)	meter	22
20.	Rubber gasket (curved)	meter	5
21.	U.V-treated polythene sheet, 3m wide, 0.2 mm thick	meter	10
22.	Misc. electrical items (wire, switches, connector etc.)		
23.	Black paint (flat) and thinner		

The dryer end is fitted with a wire net of appropriate size to prevent insects and flies from entering the drying chamber. Trays to hold the products to be dried are made from aluminum frames and stainless steel wire mesh.

A biomass stove-heat exchanger assembly is placed at the inlet of the tunnel dryer to improve the reliability of the dryer and the quality of the dried product. The heat exchanger is of cross-flow type with flue gas from the stove passing through the tubes and the ambient air flowing over the tubes before entering the dryer. Five fans, each of 14 W capacity, are used to force ambient air into the dryer, through the bank of heat exchanger tubes. The 'tubes' of the heat exchanger are connected to a biomass stove at one end and a chimney at the other. Noting that the maximum permissible temperature for fruits and vegetable drying is about 60°C, the design temperature at the outlet of the heat exchanger should not be less than this value.

Eight galvanised iron (GI) pipes with outer diameter 50 mm and inner diameter 44 mm are used to provide the required heat transfer area of the heat exchanger; the tubes are arranged in a staggered manner, as shown in Figure 3.2. The tube bank is placed inside mild steel shell of length: 1.72 m, width: 0.6 m and height: 0.16 m.

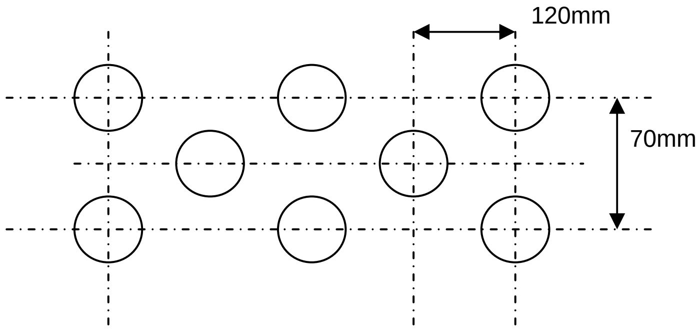


Figure 3.2: Arrangement of tubes in the heat exchanger

The stove is made of mild steel and has a cross-sectional area of 0.3m x 0.275m and height 0.4 m; it has a grate punched with 44 holes of diameter 1.5 cm. The inside walls of the stove are insulated with castable refractory cement. For supplying drying air at 70°C, the rate of briquette consumption is about 2.45 kg / hr.

The chimney, which provides the draft needed for flue gas from the stove to flow through the heat exchanger tubes, has a cross-sectional area of 0.275m x 0.16m and height 1 m.

Figure 3.3: Biomass stove-heat exchanger unit without insulation

Figure 3.3 shows the biomass stove-heat exchanger unit, with the chimney attached to it. The heat exchanger is insulated with a 100 mm thick layer of rockwool and clad with 1 mm thick aluminium sheet, to reduce thermal losses.

To reduce the uneven temperature distribution across the tunnel, two 12 V/6 W DC fans are used downstream of the heat exchanger to mix the hot air so that the air temperature is uniform across the tunnel, before it enters the dryer.

Chapter 2

PACKAGES DEVELOPED AT RECAST, NEPAL

Solar dryers of various capacities and designs are being used in Nepal for drying various agricultural, horticultural and medicinal products. The most popular dryers are box dryers, cabinet dryers, and tunnel dryers. These are being used for household and small-scale commercial drying. Except for tunnel dryers and large cabinet dryers, most dryers are based on natural convection.

Based on research carried out within the RETs in Asia programme, the Research Centre for Applied Science and Technology (RECAST) improved existing dryer designs with the following objectives: (i) to improve the thermal performance/efficiency, (ii) to reduce the capital cost, (iii) to reduce weather dependency, and (iv) to enhance the ease of operation and maintenance. The following solar dryer packages were developed: improved solar box dryer, cabinet dryer, tunnel dryer and solar/biomass hybrid cabinet dryer. The details of each package are presented in the following sections.

Package 4: Improved Solar Box Dryer

RECAST redesigned the classical solar box dryer to minimize heat losses and to facilitate easy handling. The improved box dryer consists of an insulated drying chamber and a chimney attached at the top. Window glass is used a glazing at the top of the box. The dryer, shown in Figure 4.1, has three trays on which the products to be dried are loaded. The products are spread in thin layers on the drying trays for better contact of drying air with the product. The trays are designed as drawers that can be pulled out individually for loading and unloading.

Figure 4.1: Improved Box Dryer

Design Details

The technical specifications of the improved solar box dryer are presented in Table 4.1, while its dimensional details are given in Figure 4.2.

Table 4.1: Technical specifications of the improved box dryer

Sl. No.	Parameter	Specifications
1.	Mode of drying	Direct
2.	No. of glazing	Single
3.	Loading	Pulling the drawer from backside
4.	Air outlet	Chimney at the top
5.	Air circulation	Natural
6.	Drying area	0.8 m^2
7.	Glazing slope	30 degrees
8.	Collector area	1m^2
9.	Drying capacity	4 kg-fresh per batch
10.	Construction materials	Wood, steel section, aluminum sheets, glass sheet and glass wool
11.	Approximate cost	NRs. 8,000*

*1 US$ = 74 NRs (Nepalese Rupees), March 2004

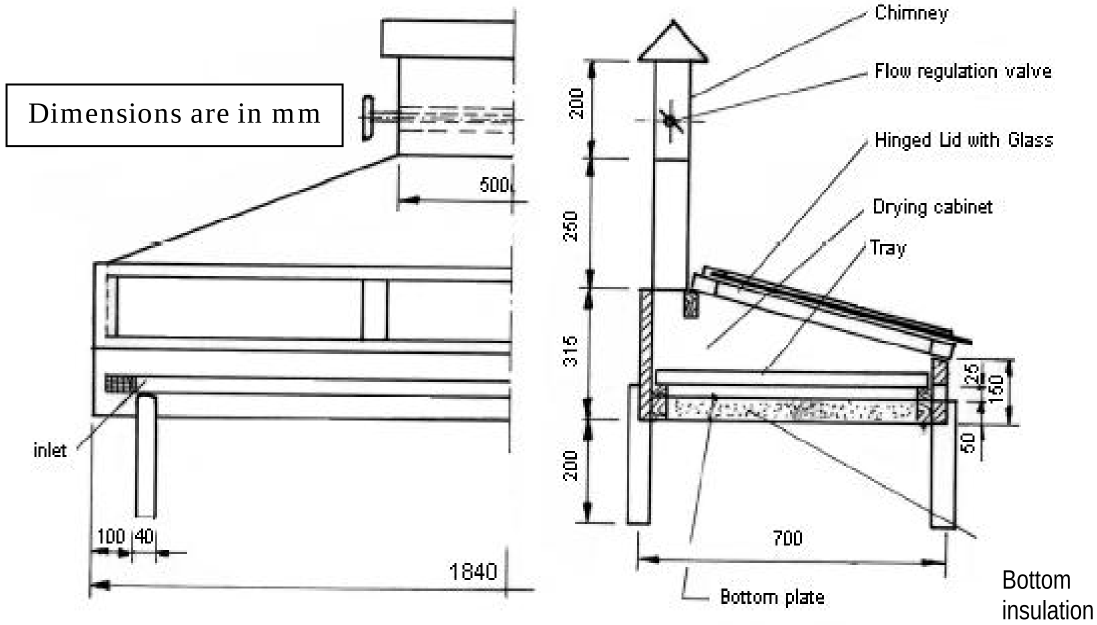
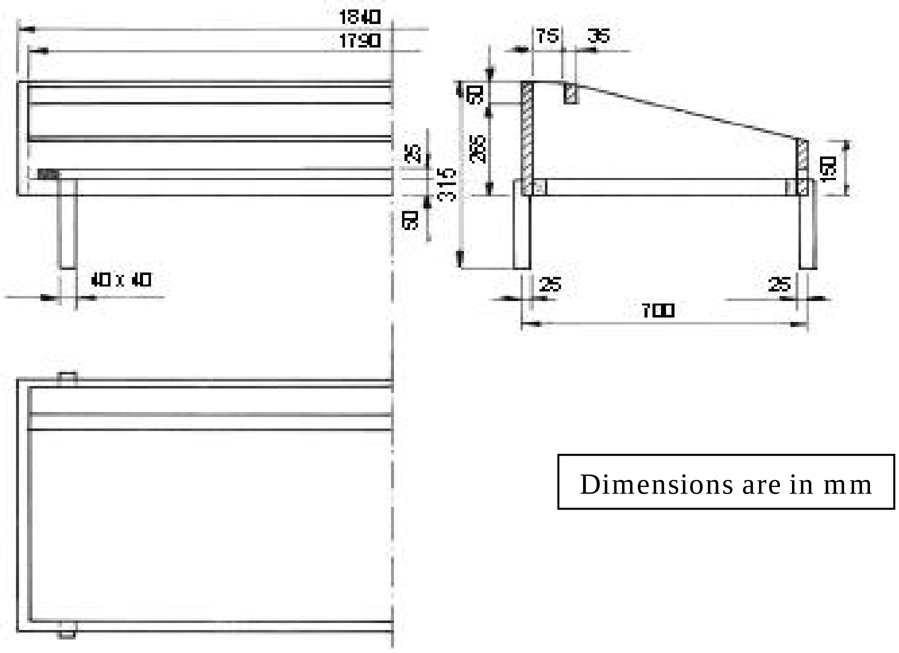
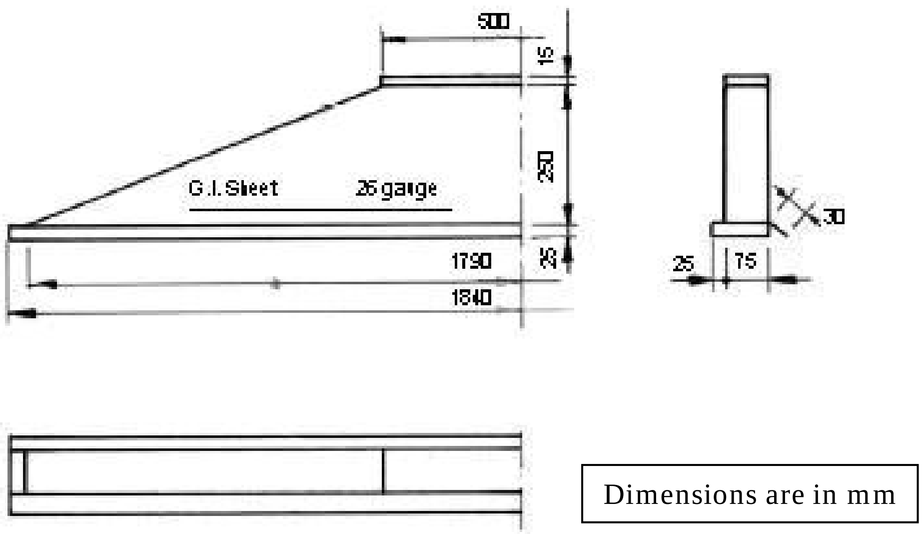


Figure 4.2: Dimensional details of the improved box dryer

The drying chamber, which is made of wood, is 0.7m x 1.84m in cross-section and has a height of 0.315 m. Figure 4.3 illustrates the dimensional details of the improved box dryer. The drawer type tray design reduces the heat loss from the dryer during loading and unloading. Warm moist air inside the box exits through a chimney installed at one end of the box at the top. The draft created by the chimney facilitates better flow of ambient air into the box and exhaust of moist air from inside the box.



(a) Drying chamber



(b) Chimney

Figure 4.3: Dimensional details of the drying chamber and chimney

The dryer has been tested for drying radish, carrot, ginger, mushroom, potato and pumpkin, and the performance was found to be good.

Package 5: Improved Solar Cabinet Dryer

To eliminate some of the drawbacks experienced in the classical solar cabinet dryers, RECAST incorporated some modifications and improved the design. The improvements were mainly aimed at enhancing the thermal performance and operational convenience, and reducing the cost.

Design Details

The improved solar cabinet dryer consists of an air-heating solar collector, a drying chamber, and a chimney attached to the drying chamber at the top. Ambient air is heated by the solar collector, and the hot air is passed through the drying chamber where products to be dried are loaded. The products are spread into thin layers on several trays inside the drying cabinet, to facilitate better contact of drying air with the product. Warm moist air from inside the drying chamber exits to the atmosphere through the chimney at the top, assisted by draft created in the chimney.

The dryer was constructed using wood sections, GI sheets and aluminium sheets. Window glass was used as glazing for the solar collector, and glass wool for thermal insulation. Mild steel angles were used for fabricating the frames. Table 5.1 presents the technical details and design parameters of the dryer, while Figure 5.1 shows the photograph and isometric view.

Table 5.1: Technical specifications of the improved solar cabinet dryer

SI. No.	Parameter	Specifications
1.	Solar collector type	Flat plate air-heating solar collector
2.	No. of glazing	Single
3.	Loading	Opening of doors at backside
4.	No. of trays	9
5.	No. of doors	3
6.	Air circulation	Natural
7.	Height of stand	1 m
8.	Collector area	3.2 m^2
9.	Drying capacity	10 kg-fresh
10.	Construction materials	Wood, steel section, aluminum sheets, GI sheets, window glass, glass wool, aluminium screws & rivets
11.	Approx. cost	NRs. 45,000

1 US$ = 74 NRs (Nepalese Rupees), March 2004

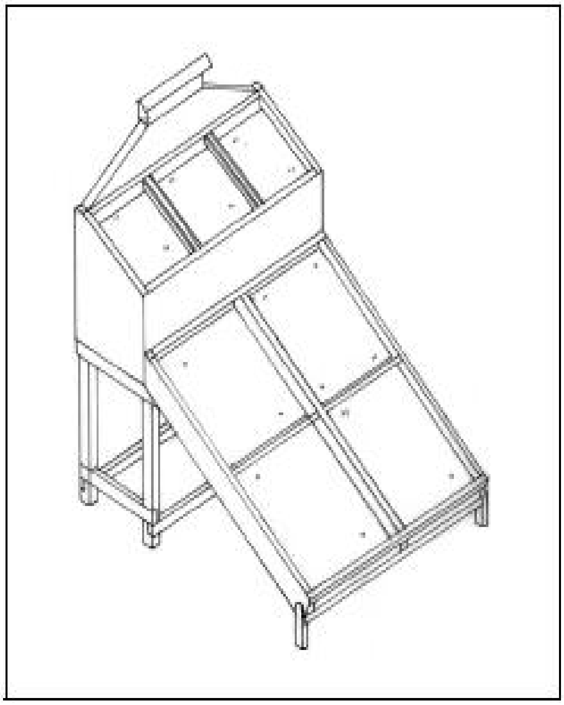


Figure 5.1: Improved solar cabinet dryer

The dimensional details of the cabinet dryer are presented in Figure 5.2. The design details of individual dryer parts are presented in the following sections.

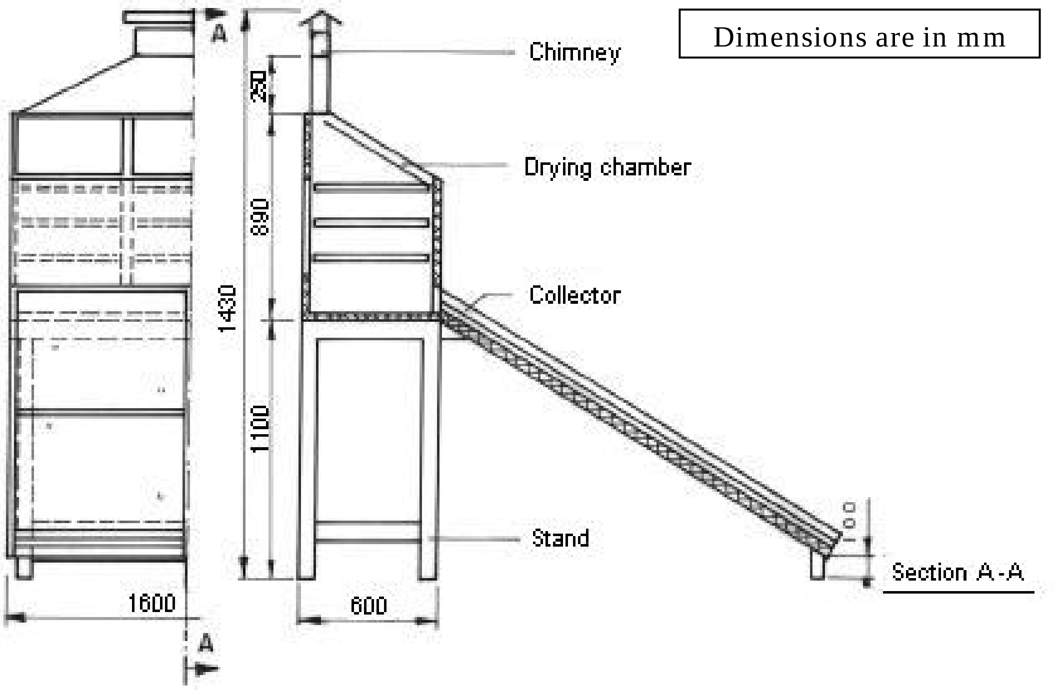


Figure 5.2: Dimensional details of the improved solar cabinet dryer

Solar Collector

The flat plate air-heating solar collector, of size 1.6m x 2m, consists of an absorber, glazing, an outer box, an inner box. A 50 mm glasswool insulation is placed between the two boxes. Corrugated aluminum sheet is used as the absorber plate, while the outer and inner collector boxes are made of GI sheets. A black coating is provided on the absorber surface. The cover glazing is of four nos. of 4 mm thick window glass. The absorber and insulation materials are placed inside the inner GI box. The air inlet to the collector is fitted with a fine stainless steel wire mesh to keep insects out.

Table 5.2: Construction materials used for the solar collector

Sl. No.	Material	Dimension	Quantity	Unit
1.	Wood	110 X 40 X 2064 mm	3	Nos.
		48 X 40 X 770 mm	2	Nos.
		53 X 50 X 1600 mm	1	Nos.
		35 X 40 X 770 mm	2	Nos.
		25 X 50 X 1600 mm	2	Nos.
		25 X 25 X 770 mm	2	Nos.
2.	GI Sheet (26 SWG)	820 X 2000 mm	2	Nos.
		780 X 2029 mm	2	Nos.
3.	Aluminium Sheet (0.8 mm)	780 X 2044 mm	2	Nos.
	Aluminium Sheet (1.2 mm)	55 X 800 mm	2	Nos.
		70 X 800 mm	2	Nos.
		50 X 1000 mm	2	Nos.
		50 X 1064 mm	2	Nos.
		40 X 1000 mm	2	Nos.
		40 X 1074 mm	1	Nos.
		40 X 800 mm	1	Nos.
4.	Glass wool (50 mm thick)	800 X 2000 mm	2	Nos.
5.	U Tube Washer	¾”	14	meters
6.	Glass (4 mm)	1000 X 750 mm	4	Nos.
7.	Screws	Various sizes	100	Nos

The collector faces south at an angle of 30° to the horizontal. Table 5.2 presents the list of materials used in the construction of the solar collector.

Drying Chamber

The drying chamber is a rectangular box, of 0.6m x 0.6m cross section and 1.6m height. The chamber is made of mild steel frame, and covered on all sides with two layers of GI sheet. A 25mm slab of glass wool is provided for thermal insulation.

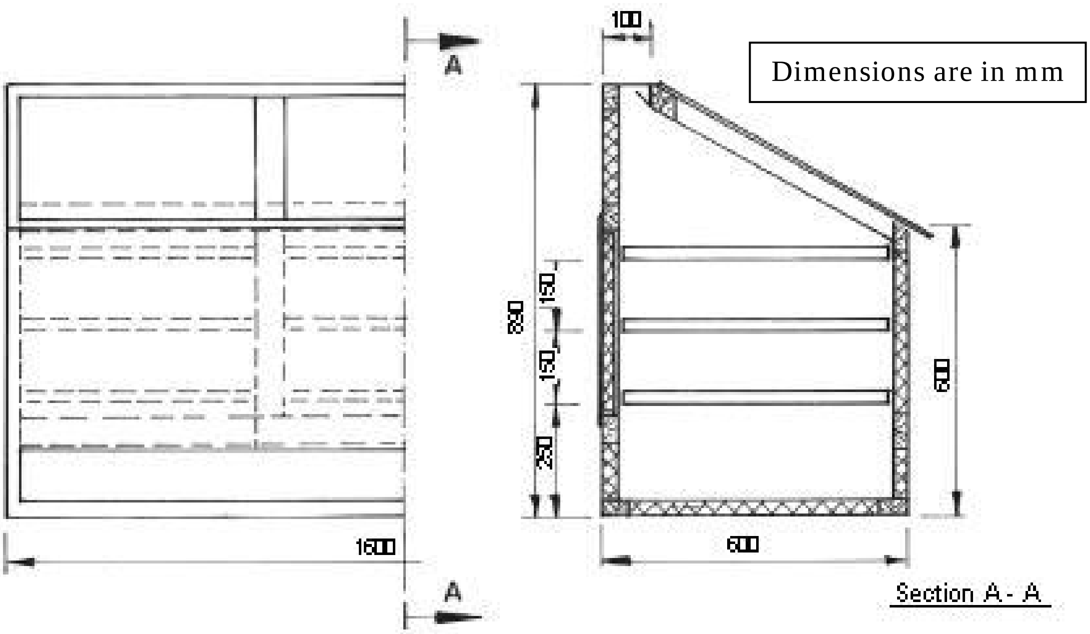


Figure 5.4: Dimensional details of the drying chamber

The drying chamber is partitioned into three columns. Nine trays, made of wooden frame and stainless steel wire mesh, are kept inside the drying chamber. These trays hold the product in thin layers, during the drying process. Each column is provided with separate doors to reduce thermal losses while handling the product inside the drying chamber during the course of drying.

The drying chamber also has three solar absorbers with glazing at the top, just below the uppermost tray. The warm air loses its heat as it acquires moisture from the product and moves along the drying chamber to the top. It requires further heating to reduce the chances of condensing and to enhance the draft effect in the chimney, which the additional solar collectors provide.

A wooden frame supports the drying chamber at the bottom. All the joints of the assembly are made airtight by fixing rubber gaskets between the joints. Figure 5.4 illustrates the design of the drying chamber.

Chimney

A chimney (0.5m x 0.075m x 0.44m), made of GI sheet, is attached at the top of the drying chamber for warm moist air exit. The chimney is provided with a roof to protect the product inside the drying chamber from rain. Detailed dimensions of the chimney are presented in Figure 5.5.

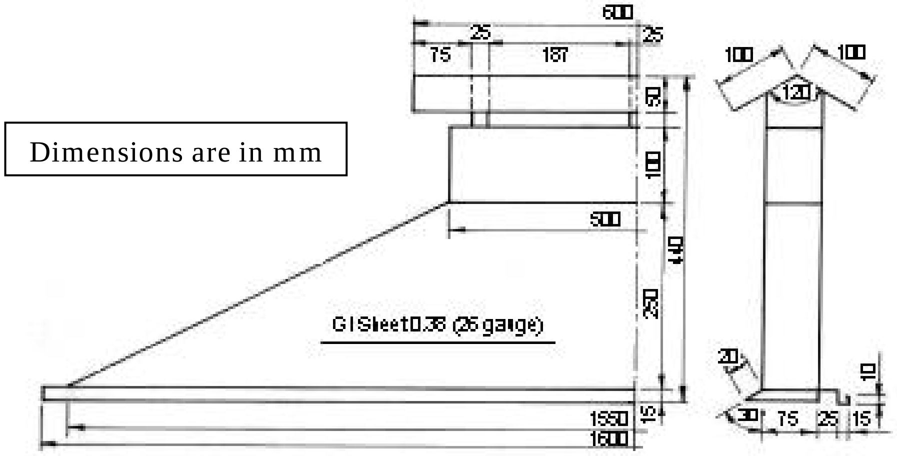


Figure 5.5: Improved solar cabinet dryer chimney dimensional details

The dryer was tested for radish, carrot, ginger, mushroom, potato and pumpkin, and found to perform well.

Package 6: Improved Solar Tunnel Dryer

The improved solar tunnel dryer consists of several flat plate air-heating solar collector modules and drying chambers connected in series in a particular layout, thus forming a 17m long tunnel. A 370W AC exhaust fan connected at the rear end of the tunnel sucks ambient air into the tunnel. Warm, moist air leaves the tunnel through the exhaust fan. Figure 6.1 illustrates the improved solar tunnel dryer.

Figure 6.1: Improved solar tunnel dryer
(split into two parts and connected using a U-connector)

Design details

The solar collector and drying chamber frames of the dryer are made of wood, insulated with glass wool, and glazed at the top with ordinary window glass, which is inexpensive and readily available in the local market. Figure 6.2 presents the configuration of the collector-dryer modules.

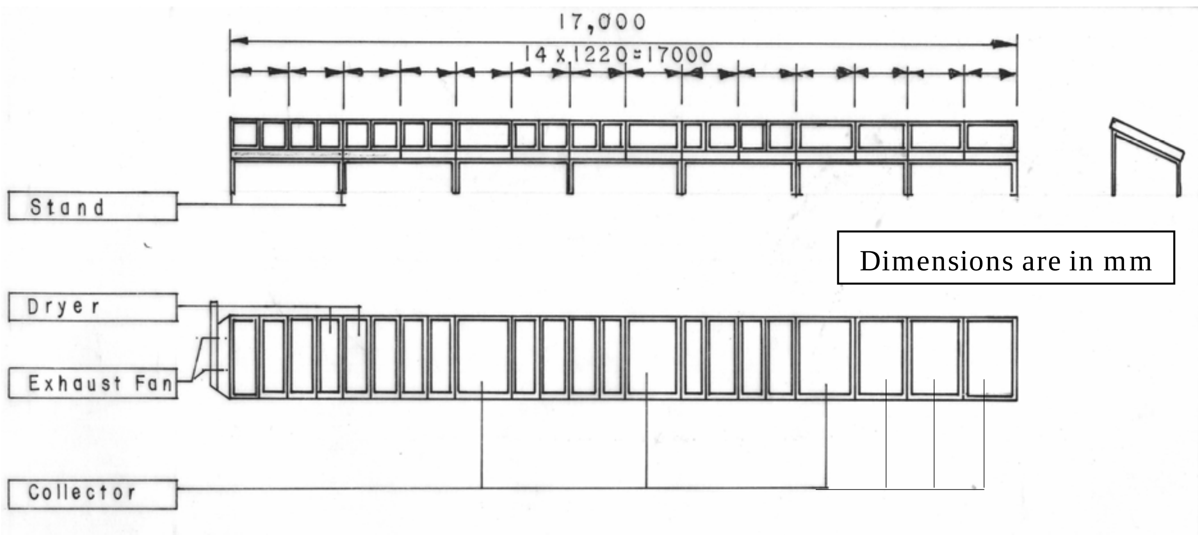


Figure 6.2: Top and side views of the solar tunnel dryer

Technical specifications of the improved solar tunnel dryer are given in Table 6.1.

Table 6.1: Technical specifications of the solar tunnel dryer

Sl. No.	Parameter	Specifications
1.	Mode of drying	Direct
2.	No. of glazing	Single
3.	No. of trays	16
4.	Air circulation	Forced, 370 W, AC exhaust fan
5.	Collector area	24 m^2
6.	Drying capacity	70 kg-fresh
7.	Construction materials	Wood, steel section, aluminum sheets, GI sheets, window glass, glass wool, aluminium screws and rivets
8.	Approx. cost	NRs. 200,000*

*1 US$ = 74 NRs (Nepalese Rupees), March 2004

Solar Collector modules

Six solar collector modules heat the ambient air forced into the tunnel by the blower fixed at one end. Four of the six collector modules are fixed at one end, next to the blower, while two collectors are located in the middle. These two solar collector modules help prevent condensation of moisture on the inner surface of the glasses, by maintaining the temperature of air inside the tunnel at reasonably high levels.

The design details of the individual solar collector modules are presented in Figure 6.3. Each module has an outer box and an inner box, with glass wool insulation between them. The collector frame is made of wood and mild steel sheet. A corrugated sheet GI absorber, coated with flat black paint, is fixed inside the inner box. 4mm thick window glasses are used for glazing the collector.

Mild steel angles provide the necessary structural support for the collector-dryer assembly.

Dryer modules

Eight dryer modules are fixed between the solar collector modules, as shown in Figure 6.2. Each dryer module has two partitions, and each partition has two trays and a glass door hinged at one side of the door frame. The glass doors can be opened at the top, for loading and unloading of the product. The trays are made of aluminum frames and stainless steel wire mesh, on which the products to be dried are loaded in a thin layer. Figure 6.4 illustrates the design of a single dryer module.

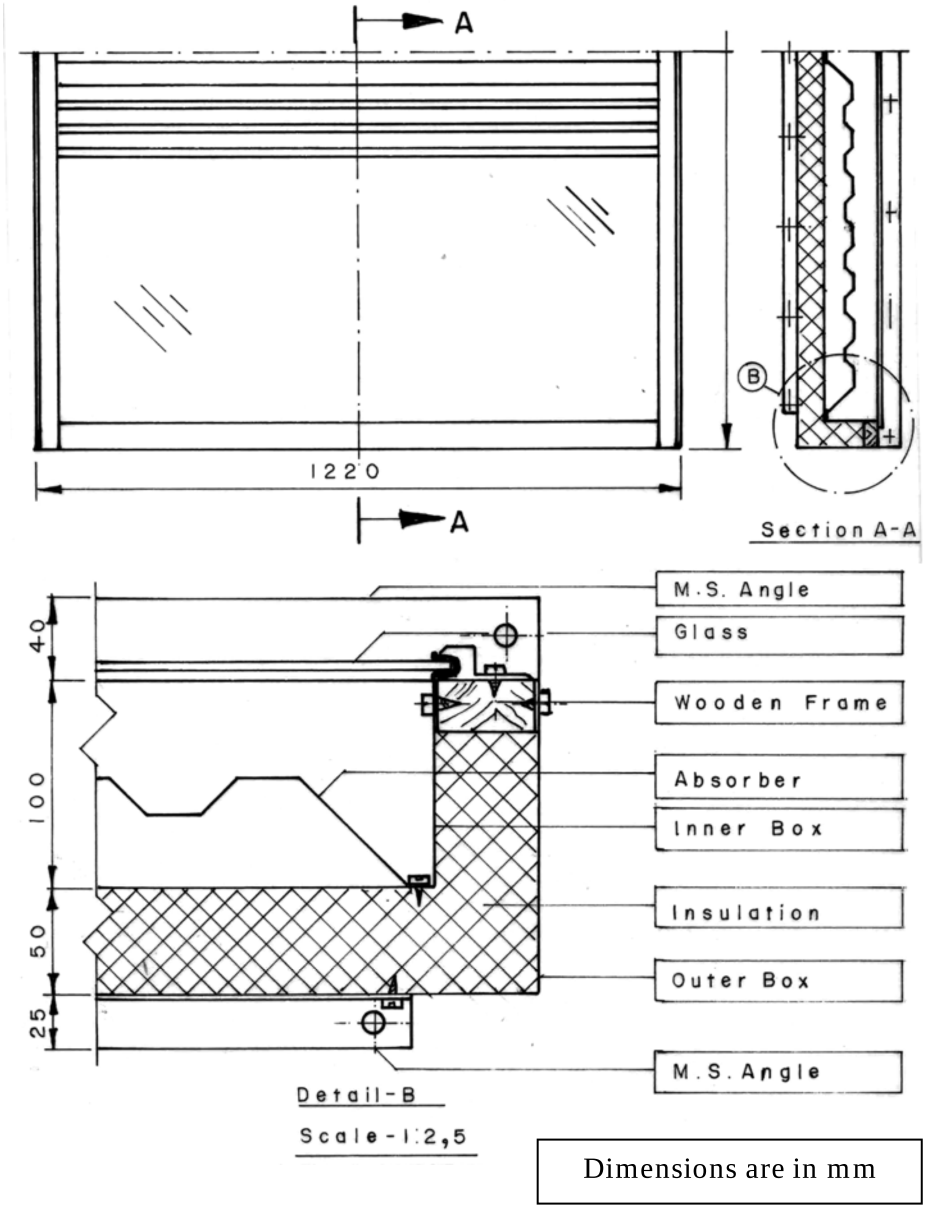


Figure 6.3: Details of a single solar collector module in the tunnel dryer

Support structure

The integrated collector-dryer unit is supported at the bottom by a steel frame, which rests on footings made of GI pipes. The footings are firmly fixed to the ground using cement concrete.

The solar tunnel dryer can dry about 70 kg of fresh vegetables in a single loading. It has been tested with several vegetables, including radish, onion, carrot, ginger and mushroom.

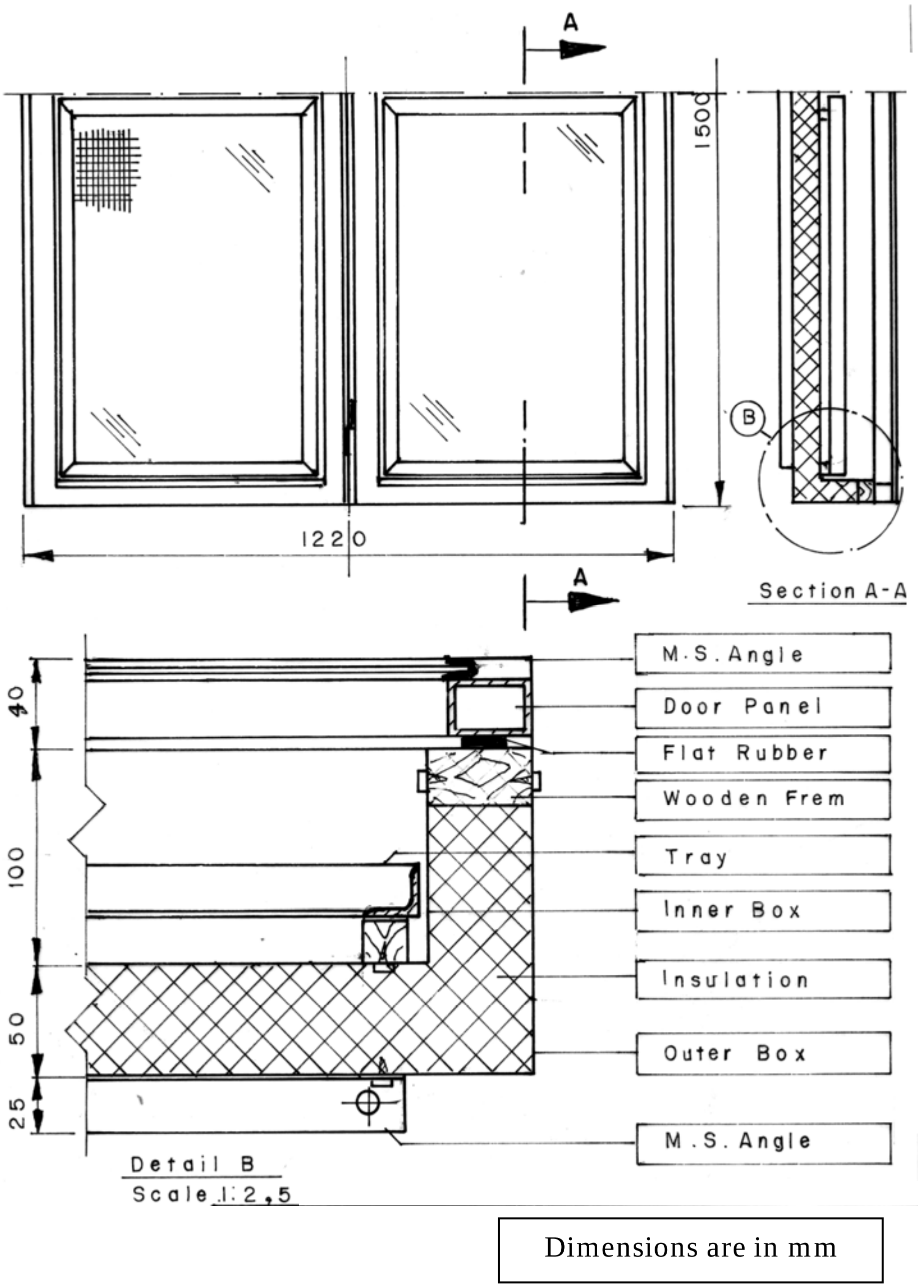


Figure 6.4: Details of a dryer module in the tunnel dryer

Package 7: Solar-Biomass Hybrid Cabinet Dryer

The hybrid cabinet dryer (Figure 7.1) consists of an air-heating solar collector, a drying chamber, a biomass stove-heat exchanger-chimney assembly, and a chimney attached to the drying chamber at the top. During daytime, ambient air is heated by the solar collector, and the hot air is passed through trays kept inside the drying chamber where products to be dried are loaded. During poor weather conditions and at night if required, the biomass stove provides the hot air required for drying. A heat exchanger is used to avoid direct contact of flue gas with the product. Direct contact of flue gas might contaminate the product as the flue gas generally contains smoke, soot, and other harmful gases.

Figure 7.1: The solar-biomass hybrid cabinet dryer

The stove can be operated using fuels such as fuelwood, wood chips, twigs, and briquettes. As honeycomb briquette is a popular fuel in certain parts of Nepal, production of honeycomb briquette is explained in detail in this package.

The products are spread in thin layers on several trays inside the drying chamber. Warm moist air from inside the drying chamber exits to the atmosphere through the chimney at the top, assisted by draft created in the chimney. Technical specifications of the solar-biomass hybrid cabinet dryer are given in Table 7.1. The dimensions of the drying chamber are optimized for convenient loading and unloading of the products. The drying chamber was also partitioned to minimize heat losses during handling of the product during the drying process.

Design Details

The hybrid dryer is a modified version of the solar cabinet dryer described in Package 5. The design of the flat plate solar collector, drying chamber, and supporting stand are similar to that already presented in Package 5. The biomass stove-heat exchanger-chimney assembly is the only addition to the solar cabinet dryer. Therefore, only the design details of biomass stove-heat exchanger-chimney assembly is described here.

Table 7.1: Technical specifications of the solar-biomass hybrid cabinet dryer

Sl. No.	Parameter	Specifications
1.	Solar collector area	3.2 m^2
2.	No. of glazing	Single
3.	Loading	Opening of doors at backside
4.	No. of doors	3
5.	No. of trays	9
6.	Air circulation	Natural
7.	Biomass stove type	Combustion type stove
8.	Fuels for stove	fuels: fuelwood, wood chips, twigs, honeycomb briquettes
9.	Stove size	0.6m x 0.3m x 0.15m
10.	Heat exchanger	Finned aluminum pipe (rectangular)
11.	Height of flue gas chimney	1.7 m
12.	Drying capacity	10 kg-fresh
13.	Construction materials	Wood, steel sections, window glass, GI sheets, aluminum sheets, MS sheets, glass wool, aluminium screws & rivets
14.	Approx. cost	NRs. 50,000*

*1 US$ = 74 NRs (Nepalese Rupees), March 2004

Biomass Stove

Honeycomb charcoal-briquettes are a popular and cheap cooking fuel in certain parts of rural Nepal. The briquettes are made by mixing charcoal and clay and moulding cylindrical briquettes with a honeycomb-like cross section. A stove which can utilise the honeycomb briquettes to supply hot air for drying was therefore thought to be an attractive option for solar-biomass hybrid dryers. This stove was developed at AIT under the RETs in Asia programme within a fellowship study by RECAST, Nepal. The honeycomb briquette stove was found to provide hot air a steady temperature of 50-60°C inside the drying chamber. Only minimum supervision was needed for the stove during operation. The dried products were also of excellent quality due to indirect contact drying.

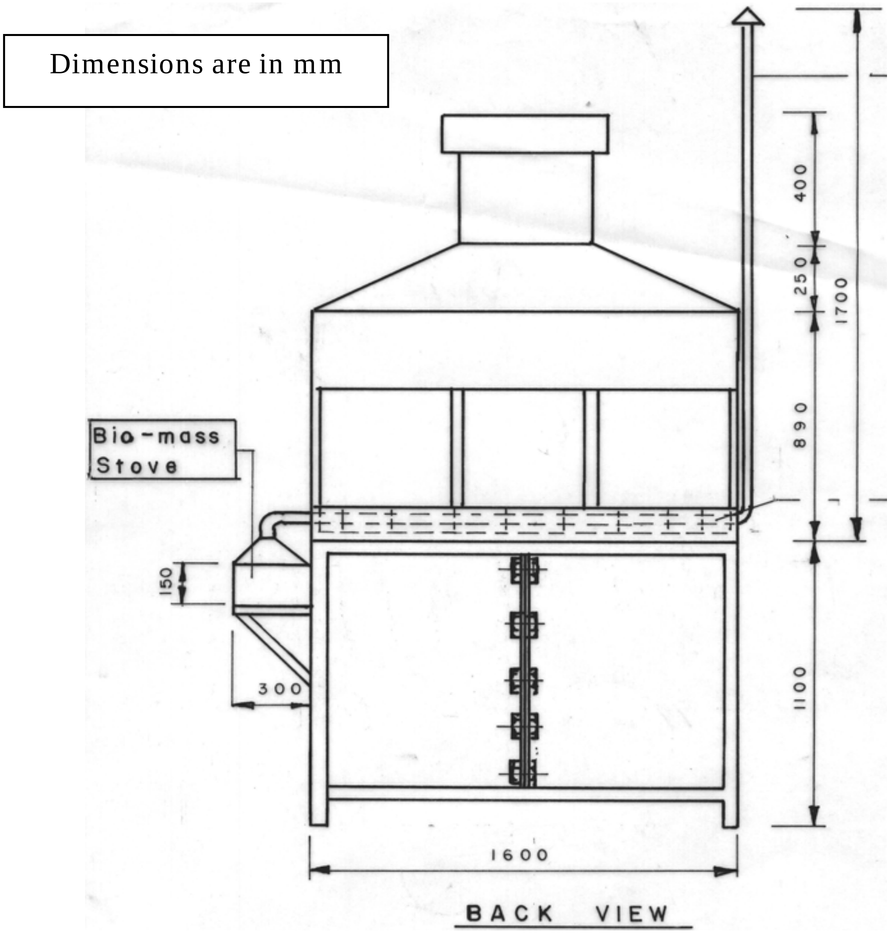


Figure 7.2: Backside view of the hybrid cabinet dryer

The stove uses cylindrical honeycomb briquettes, each of 13 cm diameter and 9 cm height, and can accommodate eight briquettes simultaneously. The stove is made of 2 mm thick mild steel sheet and is rectangular in shape. It is 30 cm x 60 cm in size, with a height of 15 cm. A grate is fixed about 5 cm above the base of the stove. Figure 7.3 illustrates the dimensional details of the stove.

The grate is made of 5mm steel rods. The distance between two rods in the grate is 6 cm. Towards the base are four rectangular openings for the entry of primary air and also for the ignition of the honeycomb briquettes. There are rectangular sliding covers in the holes, which can be adjusted to regulate the flow of primary air. The stove is covered with a hood at the top, which is connected to the heat exchanger through a connector. The hood channels the hot flue gases from the stove into the heat exchanger unit inside the drying chamber. The stove is attached to the dryer stand with mild steel angles.

During start-up, honeycomb briquettes are placed over the grates, and ignited from the bottom using a flame torch. Depending on the heat requirement, one to eight honeycomb briquettes can be ignited in the stove simultaneously.

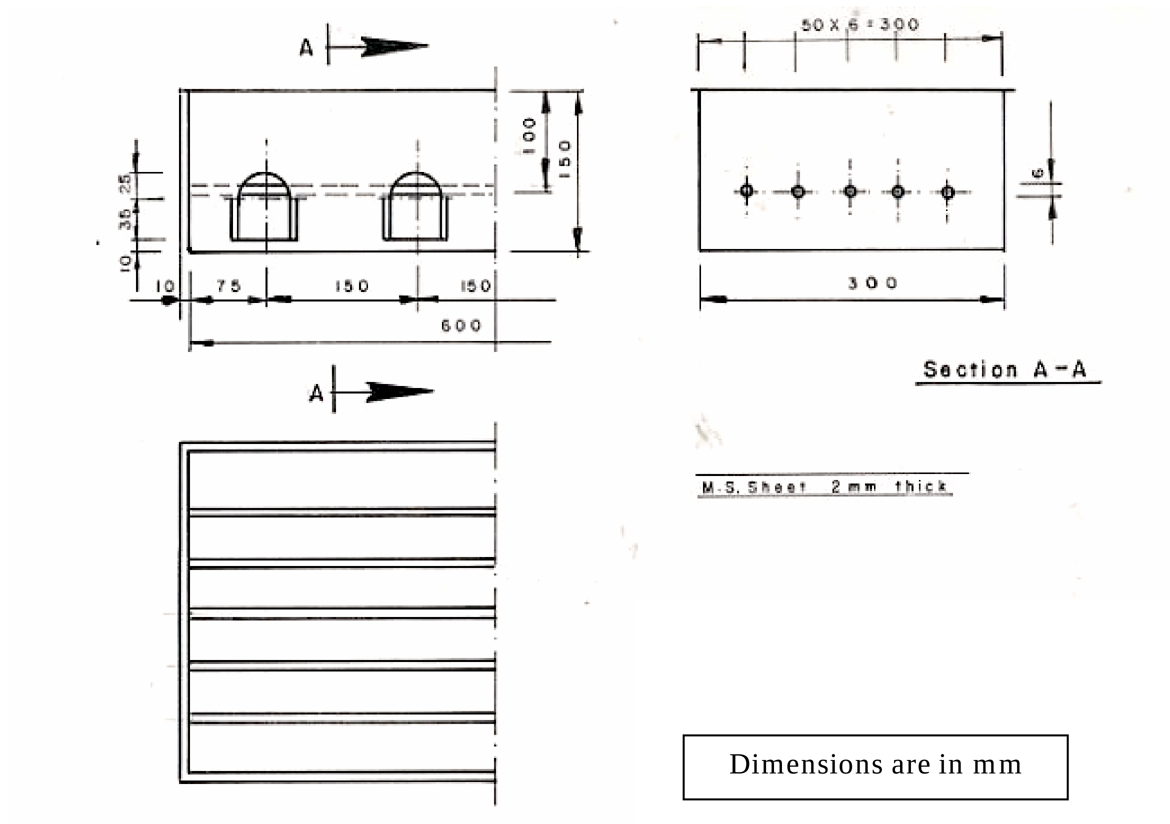


Figure 7.3: Dimensional details of the biomass stove

Although designed for honeycomb briquettes, the stove has been found to work well with other biomass fuels as well, such as fuelwood, wood chips and twigs. In locations where honeycomb briquettes are not available, this stove can thus be operated using these other fuels.

Production of Honeycomb Briquettes

The technique involves the following three stages:

(i) Partial carbonization of biomass residues,
(ii) Mixing of char with a binder, and
(iii) Briquette moulding and drying.

The procedure requires a charring drum in which the biomass is charred. The char obtained by the carbonization of biomass residues is crushed and mixed with a binder such as clay, and then briquetted in a briquette mould into cylindrical honeycomb briquettes. The details of the technique are presented below.

<u>(i) Charring Drum</u>

The charring drum can be fabricated using empty crude oil drum of 200-litre capacity. It is fitted with a conical shaped grate with fixed chimney and a top cover and water seal arrangements as shown in Figure 7.4.

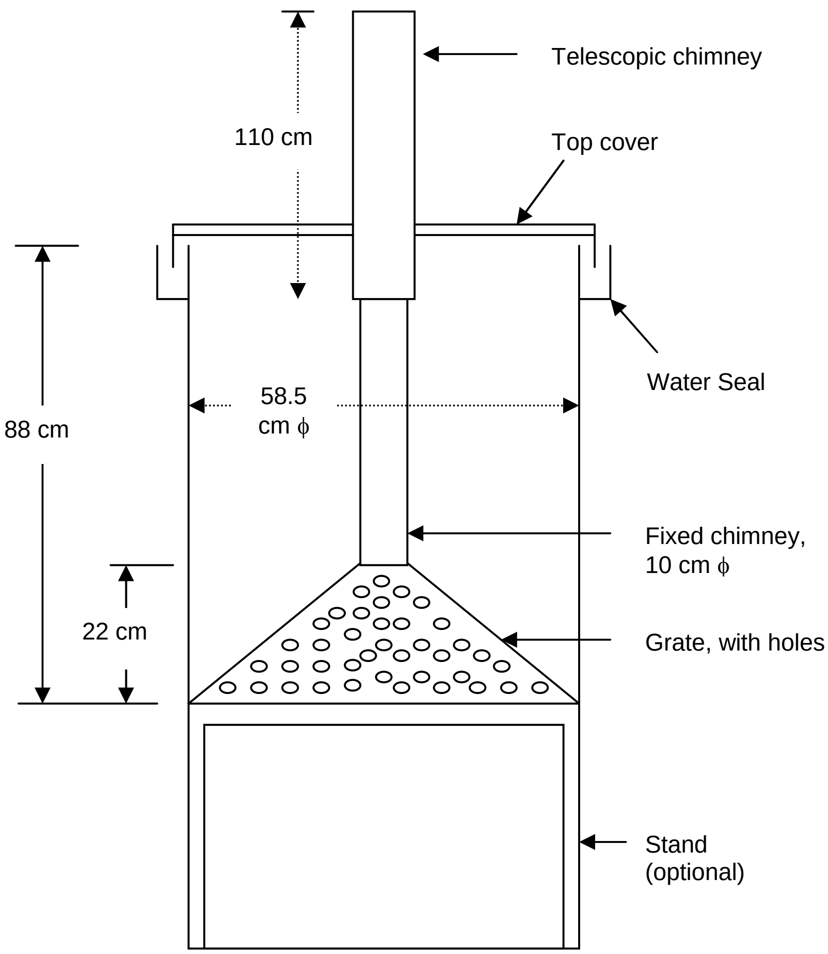


Figure 7.4: The charring drum

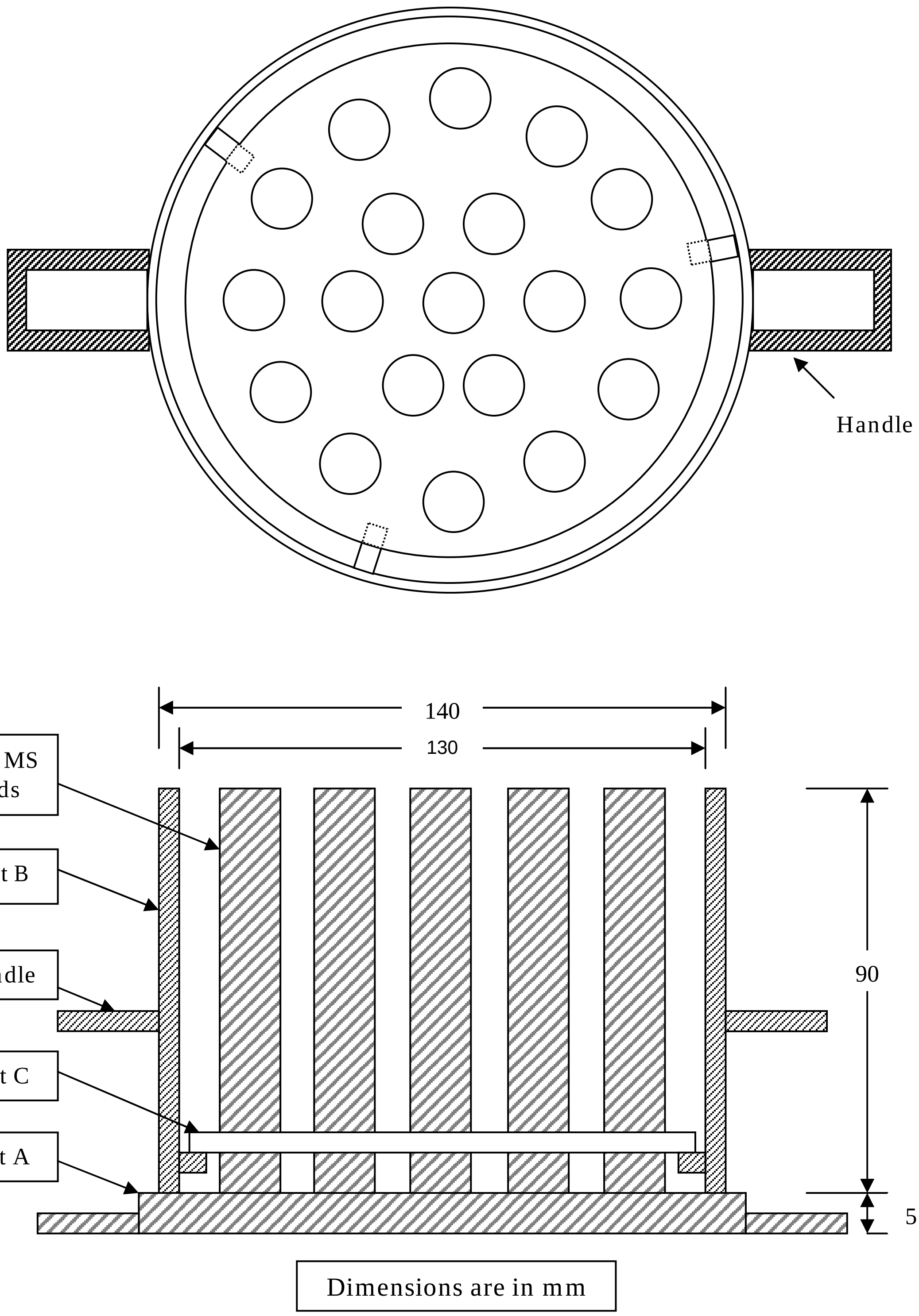
<u>(ii) Briquette Mould</u>

The briquette mould is made up of mild steel. It consists of three parts: the bottom plate with nineteen protruding rods each 13 mm in diameter, outer cylindrical cover to fit the bottom plate, and a perforated plate to slide down along the rods into the cylinder, as shown in Figure 7.5.

<u>(iii) Charring Procedure</u>

All types of biomass materials can be used in a charring drum for char production. If the biomass material is too loose (e.g.: pine needles, leaves, etc.), then they can be made into small bundles of 7-10 cm diameter and up to 60 cm length. Depending upon the type of biomass, about 40-100 kg of biomass can be carbonized in the charring drum to get a yield of 25-35% char over a period of 2 - 3 hours.

First, the conical grate with fixed chimney is placed inside the drum and the telescopic chimney is placed over the fixed chimney as shown in Figure 7.4. One to two kilograms of dried leaves or twigs are spread uniformly over the conical grate and ignited. Once the ignition starts, biomass material is added to it in small portions so that the material inside the drum does not burn fully or too fast, and turn into ash. Once the drum is full and top layer is partially carbonized, the telescopic



[Note: A, B and C are separate parts of the mould]

Figure 7.5: Briquette mould

chimney is removed and the drum is covered with its cover. Water is filled in the channel so that there is no leakage of air through the water sealing arrangement. At this stage, smoke will be released through the hole provided at the centre of the cover. When the smoke ceases to come out, the hole should be blocked by the stopper. There should be no leakage of air during cooling. The drum is allowed to cool for 2 to 3 hours before it is opened for removing the char and starting the next batch.

The biomass residues should be sized properly and sun-dried to only 10-15% moisture (wet base). Depending upon the type of biomass and its moisture content, char yields of 25-35% can be obtained. During charring, a large amount of volatiles are released so it is advisable to use these drums in open spaces. Further these drums can be easily transported to the areas of biomass availability. To get maximum production, the drum should be filled up to the top and only then the lid should be placed and water seal made. To avoid rusting of the drum, it is coated with coal tar while it is hot. Due to heat, the applied tar will crack leaving behind an impervious coating of carbon on the surface, which prevents the drum from rusting.

<u>(iv) Briquette-making</u>

The biomass char is crushed to fine powder form to get a particle size of not more than 0.8 mm. It is then mixed with 20-30% by weight of bentonite clay or local potters' clay which acts as a binder. Molasses or cooked starch may also be used as binder. The amount of water that is sufficient can be judged by taking the mixture in hand and pressing it firmly to form a ball. If a ball cannot be formed, extra water may be added to the mixture. The mixture thus obtained is covered with wet gunny bags, and is left for 24 hours for maturing.

Figure 7.6: Briquette-making using the mould

For making beehive shaped briquette from the char-clay mixture, different parts of the briquette mould set are placed one over the other in a sequence, as shown in

Figure 7.5. First, the base plate, part 'A' is placed on a levelled surface. The outer part 'B' is placed on it. Finally, the plate with 19 holes, 'C' is placed over the bottom plate 'A', in such a way that it rests on pins supports as shown in the figure.

Figure 7.7: Drying of molded honeycomb briquettes

The mould set is filled with the mixture and after filling up to the brim, the top layer is levelled with a flat wooden piece. Now, holding the handles of both part A and part B, the mould is turned upside down on to a firm ground. The mould is removed and the briquette is allowed to dry in the sun for 2-3 days. These beehive or honeycomb briquettes are superior to other briquette shapes as the honeycomb structure allows better contact between the fuel and air during combustion.

Heat Exchanger

A heat exchanger transfers heat from the hot flue gas from the biomass stove to the drying air entering the drying chamber through the solar collector. The heat exchanger, made of 24 SGW aluminum sheet, is fitted above the level of the solar collector’s air outlet. It is of fin and tube design, with a rectangular tube, on which aluminum fins are attached to enhance the heat transfer surface area. Hot flue gases from the biomass stove enter the heat exchanger at one side, and leave through a chimney at the other side. Process air which gets heated up by the heat exchanger surface, flows up through the trays which hold the products to be dried.

The dryer will be useful for commercial scale users for processing products such as fruits, vegetables and fish. The dryer has been tested for drying products such as radish, carrot, ginger and mushroom. As uninterrupted continuous drying is possible with this type of dryer, the quality of the dried product is better than that dried in the open sun or in the solar dryer.

Chapter 3

PACKAGES DEVELOPED AT UP, PHILIPPINES

Package 8: Solar-Biomass Hybrid Cabinet Dryer – FD50

The Solar Laboratory at University of Philippines Diliman (UPSL/UPD) and the Institute of Agricultural Engineering under University of Philippines Los Banos (IAE/UPLB) developed several models of renewable energy-based dryers with improved features under the RETs in Asia program, for drying fruits, fish and herbal products.

One of the dryers developed by IAE/UPLB was a cabinet type solar-biomass hybrid dryer suitable for small-scale drying applications with a capacity of about 50 kg/batch (Figure 8.1). The dryer uses a solar collector during daytime operation, and a biomass stove for operation during cloudy weather conditions and at night.

Figure 8.1: Drying chamber and biomass stove of the FD-50 Dryer

Design details

This cabinet type dryer, referred to as Model FD-50, has three main components: solar collector, drying chamber, and biomass stove. The air-heating solar collector is of flat plate type, and has an absorber area of 1.9 m^2. The drying chamber of has 30 aluminum wire net trays to hold the products. An exhaust fan powered by a 45 W electric motor fixed in the chimney of the drying chamber forces ambient air to pass through the collector. The air thus forced gets heated while passing through the collector, and rises up through the several trays on which the products being dried are spread in thin layers. The biomass gasifier stove assists drying whenever solar radiation is insufficient.

Table 8.1: Technical specifications of the hybrid cabinet dryer FD50

Sl. No.	2 Parameter	Specification
1.	Capacity per batch	50 kg sliced fruit
2.	Drying time	18 hrs
3.	Drying air temperature	up to 60°C
4.	Airflow rate	0.05 m^3/hr
5.	Dimensions	1.4×1.0×2.69 m
6.	No. of trays	30 of 0.98×0.5 m
7.	Solar collector area	2.12×0.9 m
8.	Collector air gap	0.05 m
9.	Fuel type	Coconut shell/charcoal
10.	Fuel consumption	2.0 kg/hr

Solar Collector

The solar collector has a matt black-coated GI absorber sheet, and a single Plexiglas cover positioned about 5 cm above the absorber. The metal walls of the collector box are insulated with 8 cm thick glass wool to reduce heat losses. The solar collector supplies the hot air required for dryer operation during the day time. The dimensional details of the collector are presented in Figure 8.2.

The solar collector is attached to the backside of the drying chamber at an angle of 15° to the horizontal. Hot air from the collector enters the drying chamber at the bottom and rises through the several trays which hold the products to be dried. A fan inside the drying chamber assists the flow of hot air from the collector up through the trays.

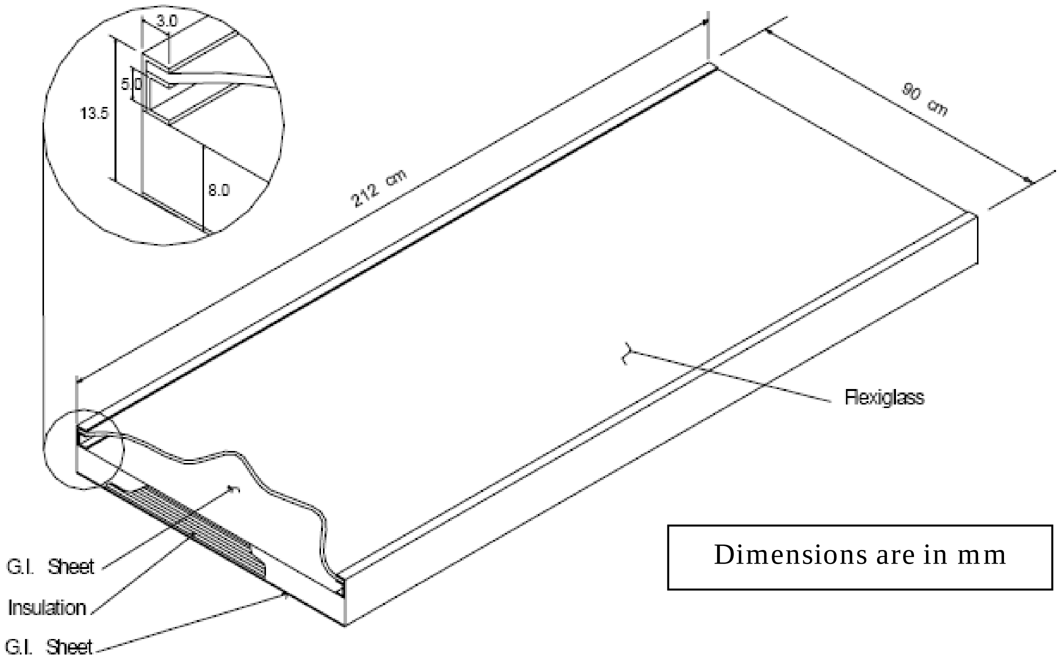


Figure 8.2: Dimensional details of the solar collector

Gasifier Stove

The design of the gasifier stove was adapted from the gasifier stoves developed at the Asian Institute of Technology. Details of this stove are given in Package 2. It consumes about 2 kg of coconut shell or wood charcoal per hour and is capable of providing drying temperatures up to 60°C. Performance tests showed that a batch of 50 kg of sliced pineapple with an initial moisture content of 85% (wet basis) could be dried to a final moisture content of 20% in about 18 hours at a drying temperature of 60°C. The total cost of the complete drying system (including the solar collector and gasifier stove) was about US$1,120 as of Feb 2002.

Package 9: Rice husk-fuelled Cabinet Dryer – FD200

IAE/UPLB developed the FD-200 cabinet type biomass dryer, which uses rice husk as the fuel. This dryer was demonstrated in a medium-scale fruit processing company, which required a fairly large drying capacity. The dryer has the capacity to accommodate 200 kg of sliced fruits.

Figure 9.1: The rice husk-fuelled cabinet dryer FD-200

Design details

The dryer consists of a drying chamber and a biomass furnace-heat exchanger unit. The biomass furnace uses ricehusk as fuel, which is fed to the furnace by an automatic feeder arrangement. An air distribution system distributes hot air evenly to the several trays inside the drying chamber. The technical specifications of the dryer are given in Table 9.1. The design of the dryer is illustrated in Figure 9.2.

Table 9.1: Technical specifications of the cabinet dryer FD200

Sl. No.	Parameter	Specification
1.	Drying capacity per batch	200 kg (sliced mango)
2.	Average drying air temperature	53°C
3.	Airflow rate	0.37 m^3/hr
4.	Dryer Dimensions	2.90 x 1.37 x 2.00 m
5.	No. of trays	52 of 0.98×0.97 m size
6.	Total tray area	48.4 m^2
7.	Fuel type, and consumption	Rice husk; 11-15 kg/hr
8.	Heat exchanger type	Shell and tube

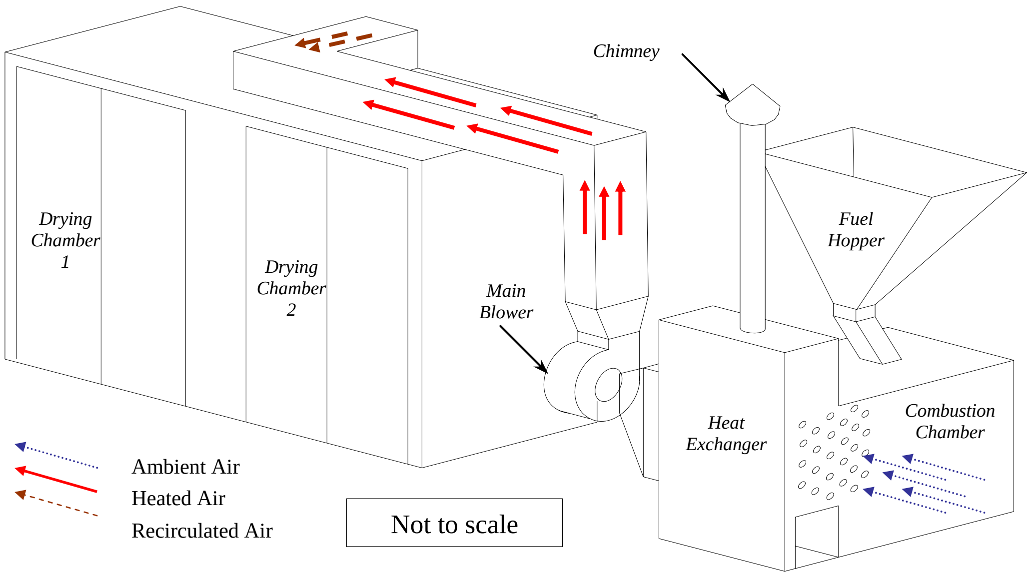


Figure 9.2: Schematic of the rice husk-fuelled drying system FD200

Drying chamber

The drying chamber, 1.37m wide, 2m tall and 2.9m long, contains two movable tray carts having 26 trays each. It is made of galvanized iron sheets framed together by angular steel bars. The trays (of dimensions 0.98m x 0.97m) are made of polyethylene plastic mesh reinforced with aluminum bars. The total area of the drying trays can accommodate 200 kg of mango slices. The chamber also has an air distribution system, which ensures distribution of air into the entire height of the chamber. The air distribution system is composed of an axial fan (with a 0.35m dia. rotor) and a distributor duct. The distributor duct has a converging shape from top to bottom, and has thirteen concentric rings of varying diameter, arranged one above the other, at specific spacing. This system can deliver an air volume of up to 0.37 m^3/sec.

Biomass furnace - Heat exchanger

The rice husk-fuelled furnace is composed of five parts: the combustion chamber, heat exchanger system, fuel hopper, air inlet duct, and the chimney. The combustion chamber is made of bricks enclosed in galvanized sheet metal while the heat exchanger system is made of 27 boiler tubes arranged in a rectangular array. All other parts of the furnace are made of galvanized iron sheet. A butterfly valve controlled by a variable speed electric motor (0.5 hp) controls the feed rate of rice husk; the fuel hopper is inclined at 45º (angle of repose of rice husk) to allow free flow of rice husk into the combustion chamber. An auxiliary blower (0.5 hp) was installed in the combustion chamber to supply the primary air required for complete combustion. The primary air supply to the furnace can be controlled by adjusting the opening of the blower air inlet.

The main blower installed between the furnace and the drying chamber draws the ambient air through the furnace-heat exchanger unit, and supplies hot air to the drying chamber. An S-shaped duct is installed at the air inlet to the heat exchanger. The mouth of the duct is located away from the combustion chamber to avoid suction of ashes that may otherwise contaminate the product to be dried. The fuel hopper has a capacity of three sacks of rice hull per loading which lasts for about 3 to 4 hours of dryer operation.

The dryer has been tested with mango and banana. The quality of the dried banana and mango were found to be very good, with no browning observed. The total cost of fabricating this dryer is about US$1,800.

Package 10: Transpired Collector Solar-Biomass Hybrid Cabinet Dryer

UPSL/UPD developed a hybrid solar-biomass dryer that incorporated several innovative features. . This drying system is distinct from the traditional solar dryer designs due to use of an Unglazed Transpired Solar Collector (UTC) for harnessing solar energy. The major use envisaged for this dryer was fish drying. The dryer, which can accommodate 10 kg of fish, consists of a drying chamber, a solar collector and a biomass stove/furnace.

Design details

The hybrid dryer was designed to operate with the UTC and the biomass gasifier stove as the primary heat sources. This ensures continuous operation of the hybrid dryer even during periods of inadequate solar radiation, as at night. For the UTC operation, the solar radiation incident on the UTC heats the perforated absorber plate. Convection transfers the heat absorbed by the collector to the ambient air being drawn into the UTC plenum through the perforations. The heated air from the collector is ducted into the heat exchanger shell. The heated air inside the drying chamber passes through the drying trays while picking up the moisture from the products being dried. The moist air exits the drying chamber through the exhaust vent located on top of the drying chamber. The continuous flow of air in the drying chamber has been ascertained through the use of the vent mounted exhaust fan. Varying the size of the opening of the exhaust vent through the use of dampers regulates the airflow rate.

Table 10.1: Technical specifications of the transpired collector hybrid cabinet dryer

Sl. No.	Parameter	Specification
1.	Capacity per batch	10 kg (~40 fishes)
2.	Drying air temperature	50°C (maximum)
3.	Air velocity	0.03 m/s
4.	Dimensions	0.914 m×1.829 m×0.465 m
5.	No. of trays	3
6.	Total tray area	2.9 m^2
7.	Solar collector type	Unglazed transpired solar collector (UTC)
8.	Solar collector area	2.33 m^2 (1.83 m×1.22 m)
9.	UTC air gap (plenum)	10 cm
10.	UTC perforation pitch	14.5 cm
11.	UTC porosity	1.1%
12.	Biomass stove type	Natural draft cross-flow gasifier stove
13.	Fuel for stove	Fuelwood

Solar collector

Unglazed transpired solar collectors have lower cost, and higher reliability compared to flat plate collectors. As the name indicates, UTC has no glazing, and consists of a low porosity perforated absorber plate fixed close to a back wall, which can be a vertical wall of the drying chamber. A circulating fan in the air collection duct draws ambient air near the front surface of the absorber plate through the perforations. Air is heated while passing through the perforations in the hot absorber plate. Although UTCs have slightly higher radiation losses, these are offset by other advantages such as low reflection losses, low cost, simple construction, and easy maintenance. The working principle of UTC is illustrated in Figure 10.1.

Figure 10.2 shows a photograph of the collector used in the dryer. The collector is made of two parts: an aluminium absorber plate, and a galvanized iron (GI) box which houses the absorber. The perforated absorber is constructed using plain aluminum sheet of 20 SGW (0.81mm) thickness, measuring 2.44m (length) x 1.27m (width). The absorber plate has circular perforations, with a hole diameter of 1.6mm and a pitch of 14.5mm.The box is constructed using 20 SWG (0.91mm) GI sheet, measuring 2.44m (length) x 1.27m (width), and a plenum depth of 0.10m. The total aperture area of the collector is 6.20m^2.

The collector is tilted at a slope of 45° to maximize the amount of solar radiation incident on the absorber plate. The collector is connected to the drying chamber using mild steel ducts. During operation, ambient air is drawn in by a blower through the perforations in the absorber plate. The hot air is delivered to the drying chamber through the connecting ducts.

The design parameters of the unglazed transpired solar collector are given in Table 10.2.

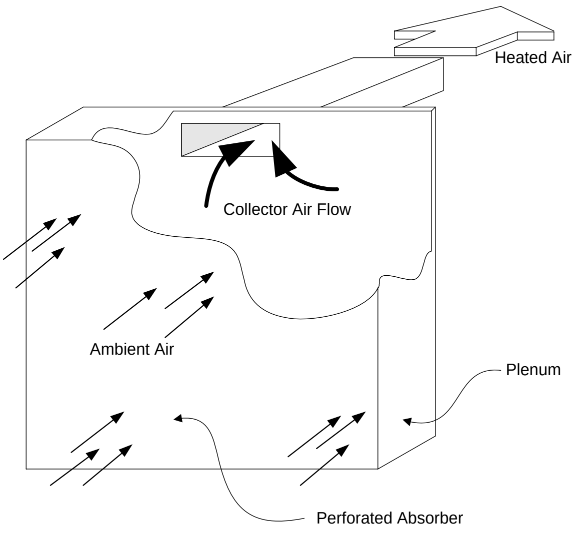


Figure 10.1: Working principle of an Unglazed Transpired Solar Collector (UTC)

Figure 10.2: The Unglazed Transpired Solar Collector used in the Dryer

Table 10.2: Technical specifications of the UTC

SI. No.	Parameter	Specifications
1.	Collector material	Galvanised Iron (GI)
2.	Collector area	6.20 m^2 (2.44 m x 1.27 m)
3.	Perforation pitch	14.5 mm
4.	Perforation diameter	1.6 mm
5.	Porosity	1.1%
6.	Plenum depth	0.1 m
7.	Blower capacity	140 W

Drying chamber

The drying chamber contains three shelves and air ducts which introduce hot air from the solar collector and the biomass furnace into the chamber at several levels. A chimney installed at the top of the chamber facilitates air circulation through the chamber.

Figure 10.3: Drying chamber of the hybrid dryer

Biomass stove

The biomass gasifier stove design was adapted from a cross-draft gasifier stove developed by AIT. The exhaust gas from the burner is channeled through a shell and tube type heat exchanger, which heats up the drying air. The optimal values of design parameters such as the plenum depth of the solar collector, airflow rate, perforation pitch, and collector area were established through experiments. All the materials used for the fabrication of the dryer were readily available in the local market. Simple design ensured that local technicians and craftsmen could carry out the fabrication. The total cost of the dryer is estimated at US$930.

Figure 10.4: The transpired collector solar-biomass hybrid cabinet dryer

Using only the solar collector, the dryer could dry fish from about 75% (wet basis) initial moisture content to 15% final moisture content in about two and a half days. However, by using both solar heat and biomass stove, the required 15% final moisture content could be achieved in 17 hours.

Chapter 4

PACKAGES DEVELOPED AT ITC, CAMBODIA

Package 11: Direct Solar Box Dryer

ITC, Cambodia designed and developed dryers suitable for family and small business use. ITC started its adaptive research by conducting a literature survey to review the existing solar dryer designs. Based on the study, ITC developed an improved version of a box type solar dryer (Figure 11.1).

Figure 11.1: Box type solar dryer

Design details

The solar box dryer consists of an outer box and an inner box, with glasswool insulation between them. The outer box of the dryer was fabricated using mild steel 'L' angles and GI sheets. The glazing at the top is hinged to the box at one edge, for easy opening and closing of the dryer during loading and unloading. Ordinary window glass was used as the glazing material. Rubber gaskets were provided at the joints to make them air-tight. A wire net was fixed at the air inlet opening to the dryer at the bottom, to keep the insects out. A mild steel stand supports the dryer at the bottom. Table 11.1 presents the technical specifications of the box dryer. The design of the dryer is illustrated in Figure 11.2.

Table 11.1: Technical specifications of the solar box dryer

Type of dryer	Direct solar
Overall size - length × width x height	152 × 70 x 15.5 cm
Aperture area	0.91 m^2
Air inlet/outlet areas	472 cm^2 each (59 cm × 8 cm)
Box material	GI sheet, 22 SWG
Tray materials	Aluminum frame; SS wire mesh
Glazing	3 mm window glass
Gap: Tray surface - Cover glass	10.0 cm
Gap: Tray surface - Dryer bottom	2.5 cm

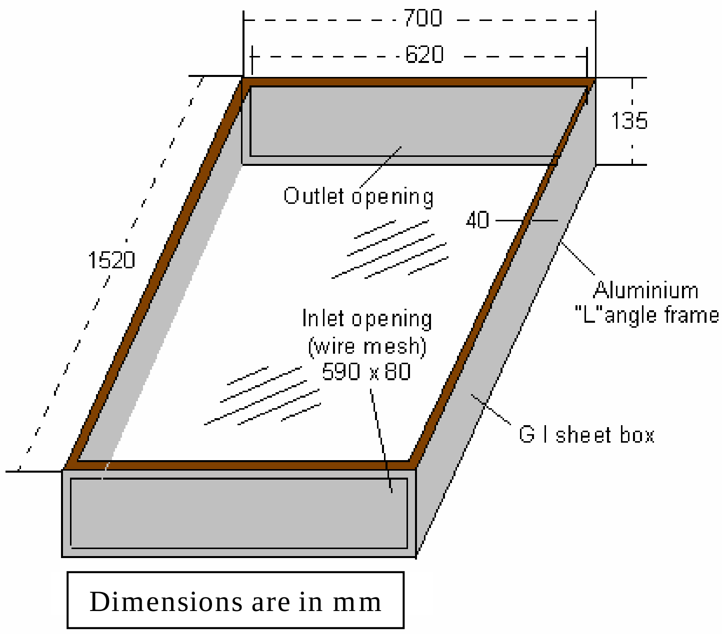


Figure 11.2: Isometric view of the box type solar dryer

The dryer operated in natural draft principle. While the hot and humid air escapes through the opening at the top, fresh ambient air enters through the bottom opening. The dryer has two trays kept inside the box for loading the products to be dried. The trays are made of aluminium angle frames and stainless steel wire mesh. The distance between the tray surface, cover glass and dryer bottom surface is kept such that air flows both above and below the tray for maximum drying effect.

The dryer box is fixed on a mild steel stand with a tilt of 20°, and placed facing south, to maximize the incident solar radiation (Figure 11.3).

Figure 11.3: Fully assembled box type solar dryer

The box dryer can be built in a simple metal workshop with facilities for cutting, bending and welding of GI sheets and mild steel angles. Fabrication is simple, and requires only regular technicians and welders, with limited guidance.

The dryer can dry banana to the required final moisture content within two and a half days. Drying of fish takes about three and half days. The products dried in the box type dryer are of better quality than those obtained with the cabinet dryer or open sun drying. However, on clear sunny days, the temperature inside the dryer can be too high for drying fish. Fabrication of this box type dryer costs around US$180.

Package 12: Chimney-type Solar Cabinet Dryers

The cabinet dryer developed consists of a rectangular drying chamber supported on a wooden base frame. The base of the drying chamber was made of a papyrus mat covered with black plastic sheeting laid inside the frame. The air inlet into the chamber is from a ventilation slot at the bottom, which is covered by a mosquito mesh to prevent insects from entering the dryer. The front side of the drying chamber has two hinged doors to provide access for loading and unloading the trays. An air outlet vent is provided at the top of the chamber to allow the exit of warm moist air, which rises by natural convection. ITC designed two versions of cabinet dryers, one with a 1 m^2 solar collector and the other with a 2 m^2 collector.

(a) 1 m^2 solar cabinet dryer

(b) 2 m^2 solar cabinet dryer

Figure 12.1: The chimney type solar cabinet dryers

Table 12.1: Technical Specifications of the Solar Cabinet Dryers

Parameter	Dryer model 1 sq. m	Dryer model 2 sq. m
Width	1 m	2 m
Collector length	1 m	1 m
Dryer length	1 m	1 m
Collector area	1 m^2	2 m^2
Tray area	1.96 m^2	3.92 m^2
Average drying capacity	70 kg	140 kg

Design details

The dryers consist of four main parts: a base frame, drying chamber, drying trays, and loading door. The rectangular base frame is built with softwood, and has supporting legs on which rests a drying chamber. A solar collector is attached to the drying chamber at the bottom. The drying chamber of the 1 m^2 model measures 1 m length x 1 m width x 0.75 m height, and contains 4 trays of 1m x 0.495 m to provide a total drying area of 2 m². The drying chamber of the 2 m² model measures 1 m length x 2 m width x 0.75 m height, and contains 8 trays of 1m x 0.495 m to provide a total drying area of 4 m². Figure 12.2 presents the dimensional details of the 1 m² model cabinet dryer.

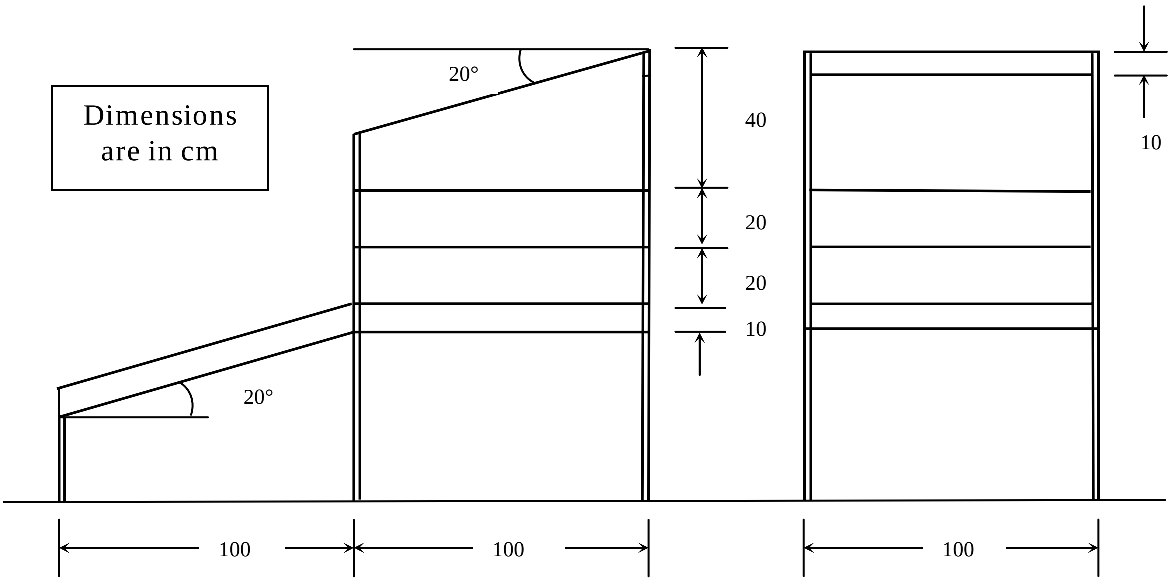


Figure 12.2: Dimensional details of the solar cabinet dryer (1 m² model)

Within the base frame, a mat made from papyrus is laid and covered over with black plastic sheet to form the base of the drying chamber. Along the back of the frame, a ventilation slot is made to form the air inlet vent to let the air enter the collector and the chamber. The vent is covered with plastic mosquito mesh to keep out insects. The solar collector heats the ambient air, which then passes through the products to be dried (loaded on trays) by natural convection.

Figure 12.2: Base frame of solar cabinet dryer – 1 m² model

Tables 12.1 and 12.2 present the list of materials and cost details for fabrication of the 1 m^2 and 2 m^2 models of the cabinet dryer. The cost of fabricating the 1 m^2 model box dryer is about US$ 80 while that for the 2 m^2 model is about US$ 120.

Table 12.1: List of materials and cost details for fabricating the 1 m^2 model dryer

No.	Item Description	Unit	Quantity	Unit Cost (US$)	Total Cost (US$)
1.	Wood: (W x L x H) - [(0.05 x 0.05) x 1.5] m	Pieces	4	1.47	5.90
	- [(0,05 x 0.05 x 1.0] m	Pieces	22	0.99	21.76
	- [(0,05 x 0.05 x 0.5] m	Pieces	7	0.52	3.65
	- [(0,015 x 0.05 x 1.0] m	Pieces	30	0.17	5.18
	- [(0,015 x 0.015 x 1.0] m	Pieces	12	0.05	0.62
2.	Clear Plastic Sheet	m	8	1.82	14.56
3.	Black Plastic Sheet	m	1.70	1.30	2.21
4.	Aluminum Mosquito Mesh	m	2.50	3.00	7.50
5.	Bending Plastic	m	33	0.18	6.00
6.	Staples	-	-	-	0.76
7.	Nails	-	-	-	1.60
Materials cost: US $ 70;		Labor cost: US $ 10;		Grand total: US $ 80	

Table 12.2: List of materials and cost details for fabricating the 2 m^2 model dryer

No.	Item Description	Unit	Quantity	Unit Cost (US$)	Total Cost (US$)
1.	Wood: (W x L x H) - [(0.05 x 0.05) x 1.5] m	Pieces	6	1.47	8.82
	- [(0,05 x 0.05 x 1.0] m	Pieces	16	0.99	15.84
	- [(0,05 x 0.05 x 0.5] m	Pieces	9	0.52	4.68
	- [(0,015 x 0.05 x 2.0] m	Pieces	28	0.17	4.76
	- [(0,015 x 0.015 x 1.0] m	Pieces	24	0.05	1.20
	- [(0,05 x 0.05 x 2.0] m	Pieces	11	1.70	18.70
2.	Clear Plastic Sheet	m	12	1.82	21.84
3.	Black Plastic Sheet	m	2.25	1.30	2.92
4.	Aluminum Mosquito Mesh	m	4.00	3.00	12.00
5.	Bending Plastic	m	44	0.18	7.92
6.	Staples	-	1/2	-	1.14
7.	Nails	-	-	-	1.80
Materials cost: $ 102;		Labor cost: $ 18;		Grand total: $ 120	

The drying chamber is built with hardwood for strength and durability. The front of the chamber has two hinged doors to provide access for loading and unloading the drying trays, on which the products to be dried are spread. Wooden rails are provided in the cabinet frame, on which the trays slide through. The tray has a hardwood frame, and plastic mosquito mesh is stapled to it. An air outlet vent is provided at the top front side, for exit of the warm moist air through natural convection; the vent is covered with mesh to keep the insects and flies out.

Both the 1 m^2 and 2 m^2 model dryers have been tested for fish and banana drying. Temperatures of up to 52°C can be achieved in the top tray of the cabinet. The 1 m^2 model can dry about 15-20 kg of fresh fish over a period of two or three days while the 2 m^2 model can dry double this quantity. The quality of dried fish was found to be superior compared to the dried fish generally produced by open sun drying. Tests with drying banana showed that good quality dried banana could be obtained in three days.

The dryers can be built using tools usually available to carpenters. Carpenters capable of building furniture such as tables, chairs, beds etc., should be able to construct the dryer with only limited guidance.

Other publications of RETs in Asia

Technology packages: Low-cost PV System Components

Presents detailed information on the different PV system components developed under the RETs in Asia programme.

Technology packages: Screw-press Briquetting Machines and Briquette-fired Stoves

Presents detailed information on the different renewable energy based drying systems developed under the RETs in Asia programme.

Demonstration and Monitoring of PV Systems: Lessons Learned

Presents the monitoring methodology of the PV systems installed under the RETs in Asia programme with an analysis of monitoring results, and includes the lessons learned.

PV System components: Technology Fact Sheets

Presents a directory of PV system/components available in the five Asian countries: Bangladesh, Cambodia, Lao PDR, Nepal and Vietnam.

Renewable Energy Technology Promotion: Case Studies from six Asian Countries.

Presents selected cases from the RETs in Asia programme. This details the technical, financial and management aspects from the different case studies in biomass briquetting, drying and PV technologies, and their applications.

For further information:

Prof. S. Kumar
Coordinator, *RETs in Asia* Programme
Energy Field of Study
Asian Institute of Technology
P.O. Box 4, Klong Luang
Pathumthani 12120, Thailand
Fax: +66-2-524 5439
E-mail: kumar@ait.ac.th

Renewable Energy Technologies in Asia: A Regional Research and Dissemination Programme

'Renewable Energy Technologies in Asia: A Regional Research and Dissemination Programme (*RETs in Asia*)' was initiated in 1997 with the broad aim of contributing to sustainable development of the Asian region by promoting selected mature/nearly mature renewable energy technologies.

The programme activities, namely adaptive research, demonstration and dissemination were carried out in Bangladesh, Cambodia, Nepal, Lao PDR, Philippines and Vietnam, and at the Asian Institute of Technology (AIT).

The renewable energy technologies/accessories considered in the programme included development of solar dryers, solar-biomass hybrid dryers, PV solar home systems, PV systems for community uses, improved PV accessories and appliances, improved biomass briquetting systems, biomass briquette stoves and gasifiers. These were designed and adapted to the local conditions and requirements. Demonstration systems were installed to promote awareness on the technical and financial viability of Renewable Energy systems. Construction, operation and maintenance manuals of the developed devices were prepared and disseminated to entrepreneurs and users. Technology transfer programs were organized among the participating institutions. Training programs were conducted for entrepreneurs, users and technicians. Results of the programme were disseminated to researchers, policy makers, entrepreneurs and users through publications, conferences, seminars and other media.

The 'Renewable Energy Technologies in Asia: A Regional Research and Dissemination Programme' was supported by the Swedish International Development Co-operation Agency (Sida) and coordinated by the Asian Institute of technology (AIT).

http://www.retsasia.ait.ac.th