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BOX TYPE SOLAR COOKER

TRAINING IN ALTERNATIVE ENERGY TECHNOLOGIES

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INTRODUCTION :

Fast depletion of non-renewable fossile fuels has generated acute energy crisis all over the world, specifically in developing countries. For the populations living in towns and villages, heavy shortage of cooking fuels like coal, kerosene, cooking gas, fire wood, dung, agricultural wastes etc. is being observed. For example energy consumption for cooking in India shares 57% of the total (including industrial energy consumption in the country. In villages most of the energy consumed goes for cooking only. Very little energy is used for lighting, running machineries or other purposes. Hence the shortage of cooking fuels is a serious matter. To find out alternative sources of cooking fuel is an urgent need.

As most of the developing countries are around equator, they are gifted with fairly large amount of sunshine over many months of the year. The abundant, inexhaustible and clean energy from the sun could be one of the best alternatives for the vast and scattered populations of these countries. Domestic fuel being in priority, simple solar cooker has a very relevant place in the present fuel consumption pattern.

Solar Cooker is a device to be used by house-wives and not by any technicians. Therefore it should be very easy to operate. Moreover it should be simple to manufacture for a local artisan with locally available raw materials.

A simple, flat plate, box type solar cooker has been developed at Agricultural Tools Research Centre India, since 1975. It is becomming very popular

among middle class and upper middle class living in towns and villages. This design is being manufactured and marketed also by a voluntary organisation - sister concern - of A.T.R. Centre. More than 850 solar cookers are being supplied to people by February 1982, from this organisation. It can be said that about 5000 box type solar cookers are being used in India at present.

AIMS AND OBJECTIVES :

1. To fabricate and test box-type solar cooker based on the existing design of Agricultural Tools Research Centre, India.
2. To run various experiments and analyse heat transfer phenomena in the cooker.
3. To study possible improvements and material substitution.

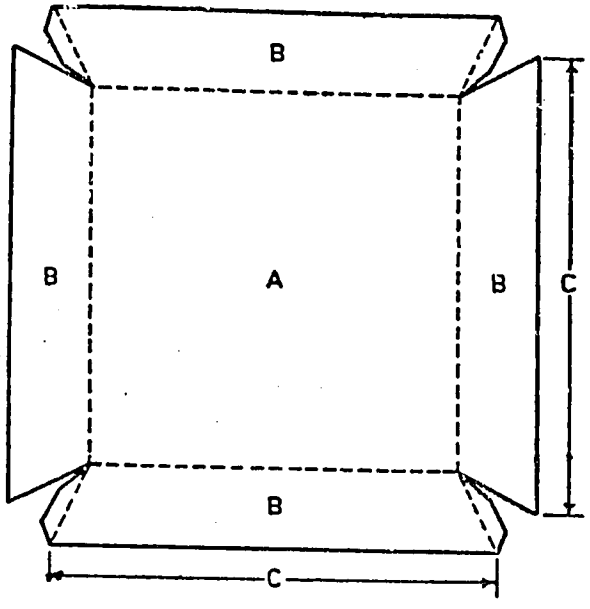
BOX-TYPE SOLAR COOKER-DESIGN

The solar cooker is made up of inner and outer metal boxes with double glass lid on it. Absorber tray is painted black with dull ~~in colour~~ and high heat resistant paint. The space between the two boxes is filled with glass wool as an insulating material. Top cover contains 3 mm. thick two plain glasses fixed in a wooden frame, keeping about 25 mm distance between the two glasses. The entire top cover can be opened as it is hinged with the outer box. When it is closed glass cover can be tight fitted with padlock hasp. Foam rubber sealing is provided around the contact surfaces of the glass cover and the cooker box. A small vent for vapour escape, is provided in the sealing.

Collector area of the solar cooker is increased by providing a plane reflector mirror, equal to the size of the box, and hinged on one side of the glass frame. A mechanism is provided to adjust the reflector at the different angles with the cooker box. When the reflector is adjusted to shine into the cooker box 15°c to 25°c rise in temperature is achieved inside the cooker box. This box type solar cooker is termed as family ~~size~~ solar cooker as it cooks about 1.25 kg. of dry food materials, which is enough for a family of 5 to 7 persons.

The detailed production design of the solar cooker is given on the next page.

Production Design of Solar Cooker

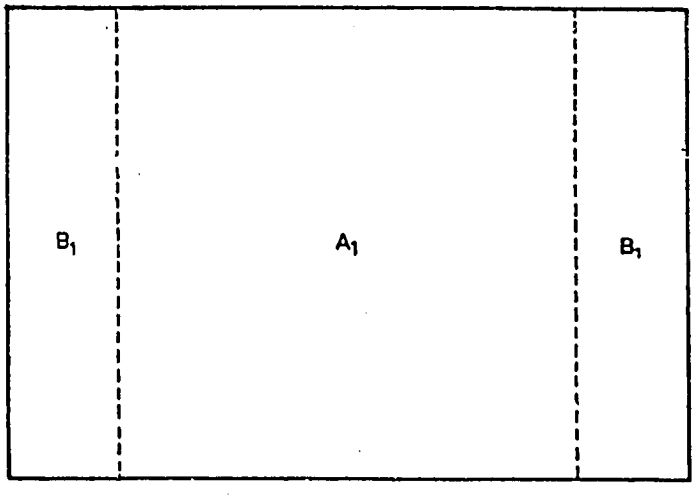


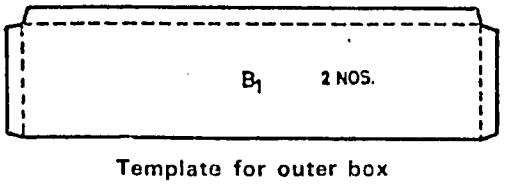
Template for absorber tray

A bottom 420 mm. x 420 mm.

B slant sides 90 mm. wide

C window opening 508 mm. × 508 mm.

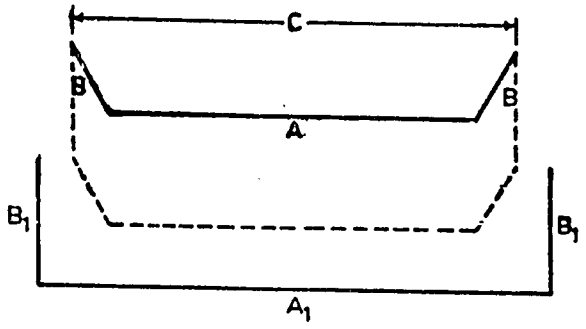




Template for outer box

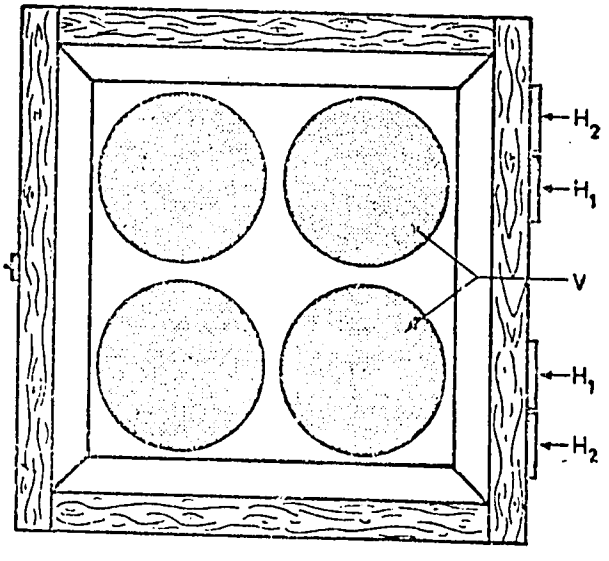
A_1 bottom 585 mm. × 585 mm.

B_1 vertical sides 585 mm. × 140 mm.

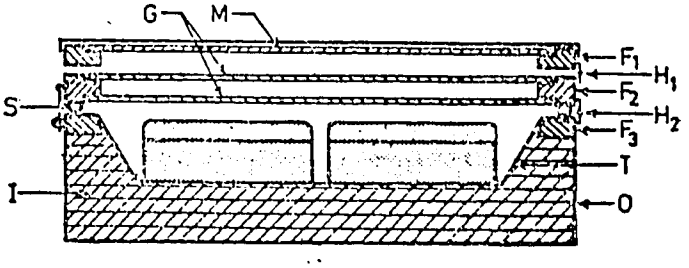


Sectional view of Absorber Tray and Outer Box

Absorber tray	Outer box
A bottom	A_1 bottom
B slant sides	B_1 vertical sides
C window opening	



Plan



Sectional elevation of solar cooker

M	mirror reflector 533 × 533 × 3	H_1, H_2	hinges
G	plane glasses 533 × 533 × 3	V	cooking utensils
S	rubber sealing	F_1, F_2, F_3	wooden frames
I	glass wool insulation	T	absorber tray
		O	outer box

All dimensions are in mm.

Designed and developed by : **Agricultural Tools Research Centre, Bardoli**
Manufacturer : Yantra Vidyalaya, P.O. Box 4, Bardoli 394 601 India

EXPERIMENTAL SET UP:

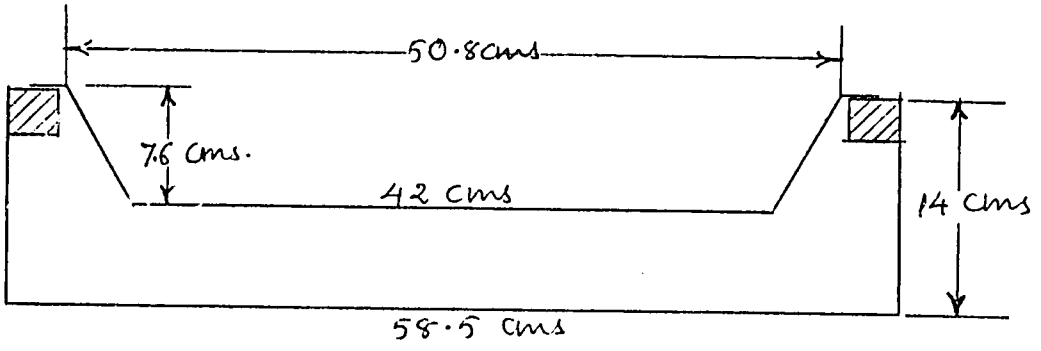
A prototype solar cooker as described above was fabricated during the TAET Program. For temperature measurements following thermocouples were setup.

Thermocouple Position	Symbol used
Centre of absorber tray	T_{PC}
at distance of 4" from centre of absorber tray	$T_{P4''}$
Centre of the upper cover glass	T_g
box sides - front, left, back, right	T_S
ambient temperature	T_a

Temperature measurements were recorded on Strip chart Recorder and Two Pan Recorder.

~~Rach~~ Solar Radiation data were recorded on Two Pan Recorder with the help of Eppley PSP or Eppley 8-48 Pyranometers.

HEAT TRANSFER CALCULATIONS



Average area of each side

$$\bar{A}_{side} = \text{Average width} \times \text{Average height}$$

$$= 52.5 \times 11$$

$$= 577.5 \text{ cm}^2$$

Average thickness of insulation on each side

$$\bar{x}_s = \frac{\left[\frac{58.5 - 50.8}{2} + \frac{58.5 - 42}{2}\right]}{2}$$

$$= 6.05 \text{ cms.}$$

Average area of bottom :

$$\bar{A}_b = \frac{58.5 + 42}{2} \times \frac{58.5 + 42}{2}$$

$$= 2525 \text{ cm}^2$$

Average thickness of insulation at bottom

$$\bar{x}_b = 6.4 \text{ cms.}$$

NO LOAD TESTING (11 MAY 1982)

During No Load Testing solar cooker was put in the sun without any cooking pots inside. Eight Copper-Constantant thermocouples were used to measure temperature at various points in the solar cooker.

On 11 May 1982, the weather was clear and sunny till noon. There were few clouds in the afternoon. Temperature measurements were carried out during 10.40 hrs to 16 hrs. Solar radiation was measured by Eppley PSP Pyranometer with a constant 10.34×10^{-6} V/W m^{-2}

Solar radiation falling on the solar cooker and heat losses are calculated for interval of one hour

Heat losses from sides and bottom of the solar cooker are calculated by conduction losses through glass wool insulation.

Average area of each side = $\bar{A}_S = 577.5$ cm^2
thickness of insulation on each side = $\bar{x}_S = 6.05$ cm.

$$Q_{L_{S_1}} = \frac{k \bar{A} \Delta T}{\bar{x}}$$ (front side), where k = Thermal conductivity of glasswool $= 0.033 \frac{W}{m\,^\circ K}$

$\bar{A} = 577.5$ cm^2

$\bar{x} = 6.05$ cm, $\Delta T = T_p - T_s$

$$Q_{L \text{ rest 3 sides}} = \frac{k \bar{A} \Delta T}{\bar{x}}$$, where $\bar{A} = 1732.5$ cm^2

$$Q_{L \text{ bottom}} = \frac{k \bar{A} \Delta T}{\bar{x}}$$, where $\bar{A} = 2525$ cm^2

$\bar{x} = 6.4$ cm

With above formulae heat losses for interval of one hour are tabulated on next page.

Time	① $\bar{T}_p$ °C	② $\bar{T}_{side_1}$ °C	③ $\bar{T}_{sides\ 2,3,4\ \&\ bottom}$ °C	ΔT ①-② °C	ΔT ①-③ °C	Q_L sides W.Hr	Q_L bottom W.Hr	Q_L sides + bottom W.Hr
10.40 - 11	160	46	37	114	123	5.1	5.34	10.44
11 - 12	169	47	40	122	129	16.02	16.8	32.88
12 - 13	171	45	42	126	129	16.15	16.80	32.95
13 - 14	164	43	42	121	122	15.33	15.88	31.21
14 - 15	152	45	42	107	110	13.78	14.32	28.1
15 - 16	162	48	43	114	119	14.84	15.49	30.33

Front Losses

All the three modes of heat transfer are occuring between absorber plate and ambient from top of the solar cooker. To simplify the calculations, ~~of~~ heat losses from top cover glass to ambient by way of convection are calculated.

$Q_{L\ top} = h\ A\ \Delta T$, where h = convective heat transfer coefficient

= 9.76 Kcal/m² °C hr

(2 Btu/ft² °F hr)

$A = .2581\ m^2$ (neglecting area of wooden frame)

Heat losses from the cover glass are tabulated below for interval of one hour.

Time	$\bar{T}_g$ °C	$\bar{T}_a$ °C	$\bar{T}_g - \bar{T}_a$ °C	$Q_{L\ top}$ W.Hr	$Q_{L\ total} = Q_{L\ sides+bottom+top}$
10.40 - 11	71.5	30	41.5	44.7	55.14
11 - 12	75	30.5	44.5	143.8	176.62
12 - 13	74.5	32	43.5	140.5	173.45
13 - 14	68.5	32	36.5	117.9	149.11
14 - 15	68	32.5	35.5	114.7	142.8
15 - 16	72.5	33.5	39.0	126.0	156.33

Total 853.45 W.Hr

Average solar radiation falling on the solar cooker for the same hour interval is tabulated below:

Time	Average Solar radiation ($\bar{I}$)	$Q_{in} = \bar{I} \times$ Area of box ($.3414\ m^2$)
10.40 - 11	718 w/m^2	81.7 W.Hr
11 - 12	805	275
12 - 13	888	303
13 - 14	920	314
14 - 15	800	273
15 - 16	805	275

$Q_{in} = 1521.7$ W.Hr

From these values' thermal efficiency of the solar cooker in no load condition can be calculated as

$$\eta = \frac{Q_{in} - Q_{Losses}}{Q_{in}}$$

$$= \frac{1521.7 - 853.45}{1521.7}$$

$$= 43.9\%$$

Thermal efficiency of the solar cooker will depend upon time of the day. In the morning the cooker is ~~at~~ cold and heat losses from the cooker are negligible compared to heat comming in. Therefore thermal efficiency will be very high. As the cooker heats up, thermal losses keeps on increasing compared to heat comming in and thermal efficiency will go on decreasing. In the afternoon as the whole cooker is heated up to a very high temperature, thermal losses are very high and efficiency may become negative value.

LOAD TEST - 12 MAY 1982

Load test was conducted primarily to analyse the modes of heat transfer to the cooking pots and eventually to the food materials inside the pots.

Two cooking pots were filled with equal amount of water ie. 750 ml. One pot was painted black from outside and another was covered with polished mylar tape, with a purpose of eliminating heat transfer to pot by direct solar absorption. Cupper - Constantant thermocouples were dipped into water in both the pots.

Both the pots were put into the solar cooker at 9-06 a.m. Water of the pot, which was painted black from outside, reached boiling point at 11-36 a.m. and that in another pot reached boiling point at 12-06 p.m. On an average it can be said that it took 2 hrs. 45 min. to boil 1.5 kg of water.

From the graph of water temperatures in two pots, it can be said that maximum difference between two water temperatures at a time was 10°C. This temperature difference and 30 minutes time difference between two water boiling, indicates that direct solar absorption is an important mode of heat transfer to the water in the pot.

Heat absorbed by water

$Q_{out} = m\, C_p\, \Delta T$, where m = quantity of water = 1.5 kg

$= 1.5 \times 1 \times (100 - 28)$

$= 108$ kcal

C_p = specific heat of water $= 1 \frac{kcal}{kg\,°C}$

ΔT = (Boiling temperature - (initial water ")

Average solar radiation during 9-06 hrs. to 11.51 hrs (2 hrs 45 min.) is

$$\bar{I} = 715 \ W/m^2 \text{ (measured by planimeter)}$$

Top area of cooker box = A = 58.5 cm x 58.5 cm
= .3414 m^2

Therefore total energy received by the cooker box over the period of 2 hrs. 45 min. is

$$Q_{in} = \bar{I} \times A \times \tau$$
$$= 715 \times 0.86 \times .3414 \times 2.75$$
$$= 577.3 \text{ Kcal}$$

∴ Efficiency of heat transfer to water is

$$\eta = \frac{Q_{out}}{Q_{in}} = \frac{108}{577.3} = 18.7\%$$

Also relative efficiencies of the two pots can be expressed as below, on the basis of heat absorbed by individual pot upto the point of boiling.

$$\eta_{Black\ pot} = \frac{m\, C_p\, \Delta T}{Q_{in}\, \tau\, A}$$

where,

m = quantity of water in black pot
= 0.75 kg

C_p = 1

ΔT = (100°C - 28°C) = 72°C

τ = Time taken to reach boiling point
= 11.36 hrs - 9.06 hrs
= 2.5 hrs.

Q_{in} = Solar radiations received by the cooker during the time period mentioned above

$Q_{in} = 646\ W/m^2$ (measured by planimeter

A = area of cooker box top

$= 0.3414\ m^2$

$$\therefore \quad \eta_{black\ pot} = \frac{0.75 \times 1 \times 72}{(646 \times 0.86) \times 2.5 \times .3414}$$

$$= 11.4\ \%$$

Similarly efficiency of silver taped pot can be calculated as

$$\eta_{silver\ pot} = \frac{0.75 \times 1 \times 72}{(687 \times 0.86) \times 3 \times .3414}$$

$$= 8.95\ \%$$

<u>NOTE</u>: The difference between two pot efficiencies is due to the heat transfered ~~to~~ to water in black pot by the mode of direct absorption which is absent in the other pot. Here it should be mentioned that by covering one pot by polished mylar tape, the mode of heat transfer by direct solar absorption was not completely cutoff. It will still absorb a small portion of solar radiation.

COSTING OF BOX TYPE SOLAR COOKER

Cost of the box type Solar Cooker would depend mainly upon cost of raw materials. To give a realist idea it would be appropriate here to give costing of the cooker (of the design described in this paper) provided by an organisation who is manufacturing and marketing the solar cookers in India since 197

Material cost	=	$ 45
Labour charges	=	$ 8
workshop charges and overheads	=	$ 22
Sales price →		$ 75 (January 1982)

Production cost of the box type solar cooker will vary from place to place and country to country according to prices of raw materials and labour charg An estimate of the materials cost of the cooker, fabricated at TREEO Centre, is given below:

	$
Sheet metal - 22 SWG Mild Steel	12.50
Wooden frames	2.00
Insulation - Glass Wool	2.00
Two cover glasses - 3 mm window glass	7.00
Reflector - mirror 6 mm thick	12.75
plywood sheet	1.25
Hardware (handles, hinges, screws etc.)	12.00
Foam rubber sealing	3.00
Total	$ 52.50

If this solar cooker is produced commercially in USA materials cost would be quite lower than the above estimated cost.

GENERAL DISCUSSION

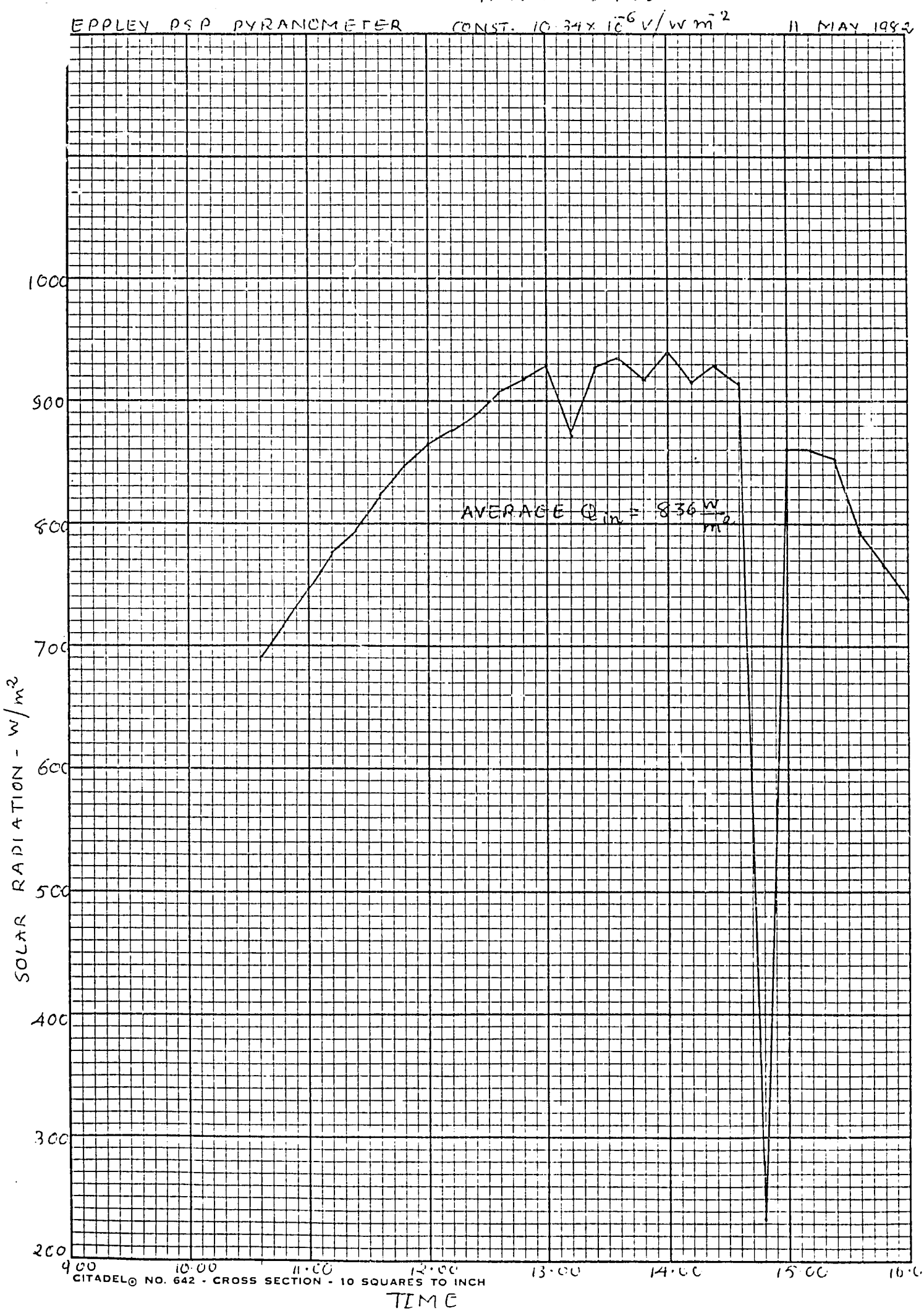
The experience of the people invalved in research and testing of the box type solar cookers is that it can meet upto 40 percent of the cooking needs of ~~the~~ ~~countr~~ India. Similar would be the case in other developing countries. For mass acceptance of solar cookers there has to be different designs of solar cookers according to climatic conditions of the place and buying capacity of the peop To begin with one will have to start with the simplest design. As cooking is totally decentralised system in developing countries, production of the cookers also needs to be in a decentralised way Local artisans need to be trained for fabricating the cookers.

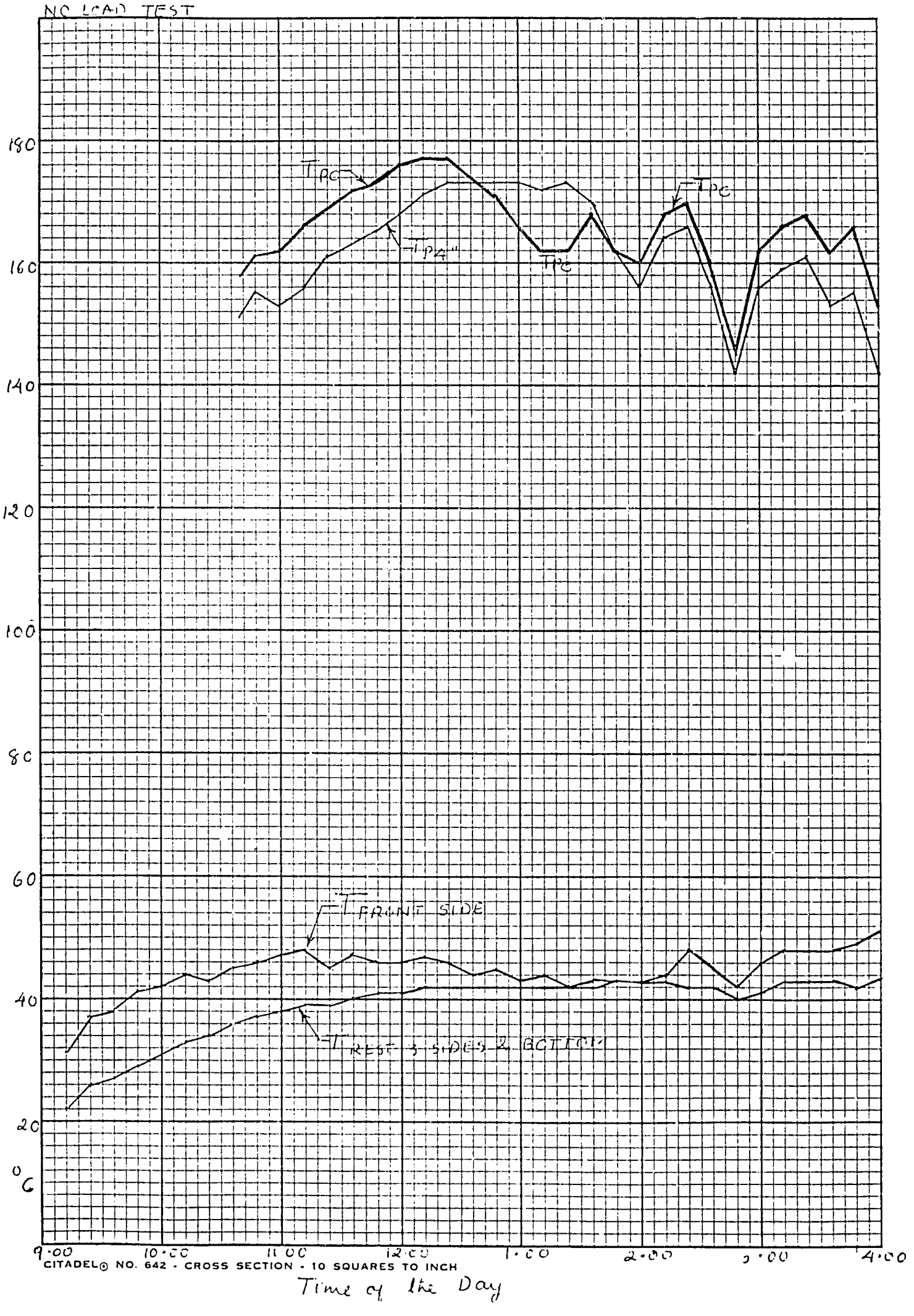
For any decentralised system every individual has to be educated and trained for the new technology. The attitude has to be developed. Once new technology is put in the practice and development process starts, the technology is open for modifications and improvements.

Equally important is the after sales service for a new technology. Dueo to lack of follow up program many new technologies did not exist longer in the past in rural areas.

ACKNOWLEDGEMENT

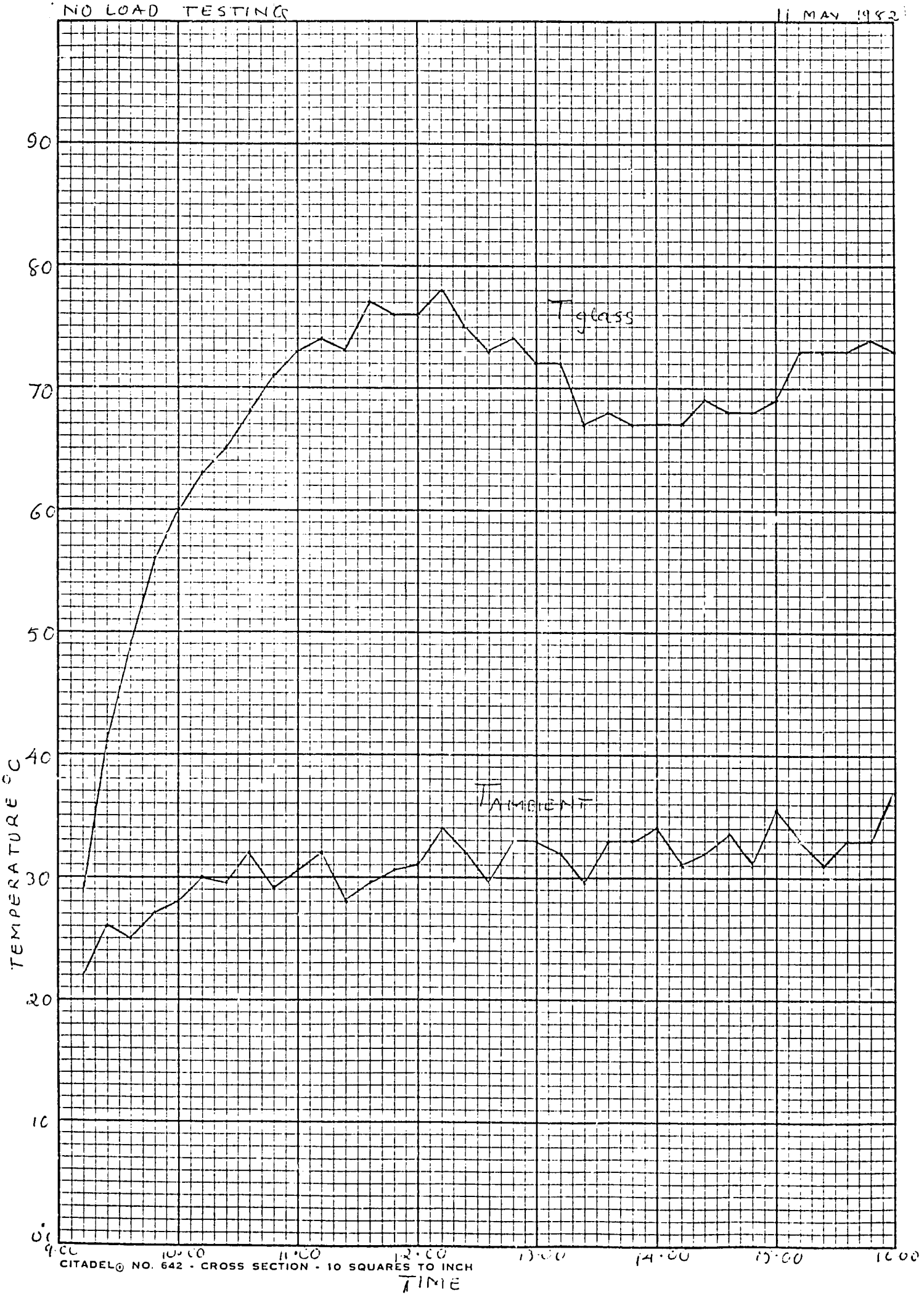
It is a pleasure to pay gratitude to Dr. Farber who provided time to time suggestions and discussions during the project work, to clarify the ideas. Also we acknowledge the help provided by Dr. Bush and Mr. Inky who took keen interest in the project and helped through the process of thinking and analysing the phenomena occuring in the solar cooker. All the help provided by the technicians, to fabricate the cooker, is also highly appreciated.


45·13 m² 5·4 Hrs
EPPLEY PSP PYRANOMETER CONST. 10·34 x 10⁻⁶ V/W m⁻²
11 MAY 1982
AVERAGE Q in = 836 W/m²
SOLAR RADIATION - W/m²
1000
900
800
700
600
500
400
300
200
9·00
10·00
11·00
12·00
13·00
14·00
15·00
16·00
TIME
CITADEL® NO. 642 - CROSS SECTION - 10 SQUARES TO INCH

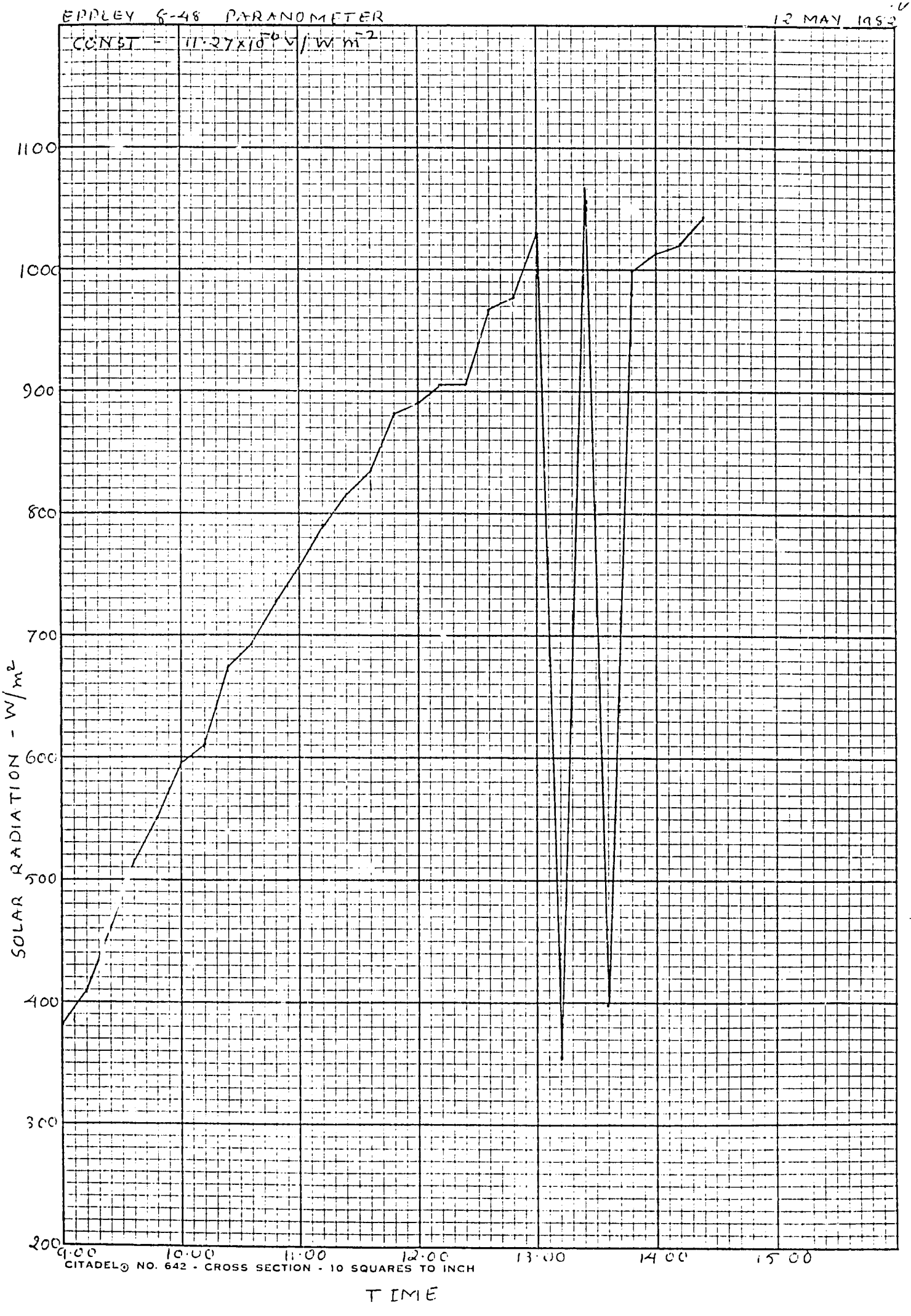

NO LOAD TEST
180
160
140
120
100
80
60
40
20
°C
T_{PC}
T_{PC}
$T_{P4''}$
T_{PC}
$T_{FRONT\ SIDE}$
$T_{REST\ 5\ SIDES\ 2\ BOTTOM}$
9·00
10·00
11·00
12·00
1·00
2·00
3·00
4·00
CITADEL® NO. 642 - CROSS SECTION - 10 SQUARES TO INCH
Time of the Day

NO LOAD TESTING

11 MAY 1982

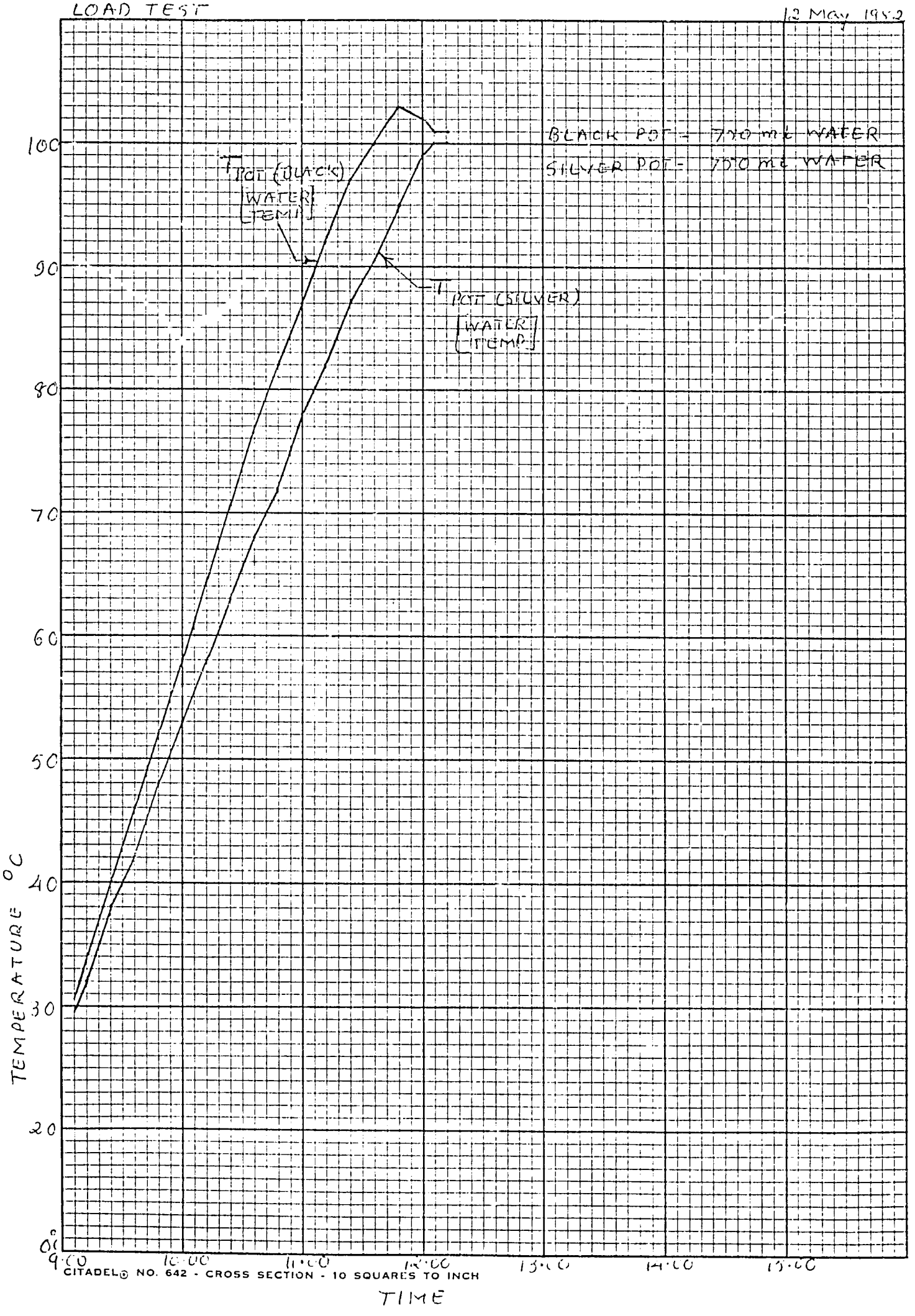


CITADEL® NO. 642 - CROSS SECTION - 10 SQUARES TO INCH


EPPLEY 8-48 PYRANOMETER
12 MAY 1952
CONST = 11·27 x 10⁻⁶ V / W m⁻²
1100
1000
900
800
700
600
500
400
300
200
SOLAR RADIATION - W/m²
9·00
10·00
11·00
12·00
13·00
14·00
15·00
CITADEL NO. 642 - CROSS SECTION - 10 SQUARES TO INCH
TIME

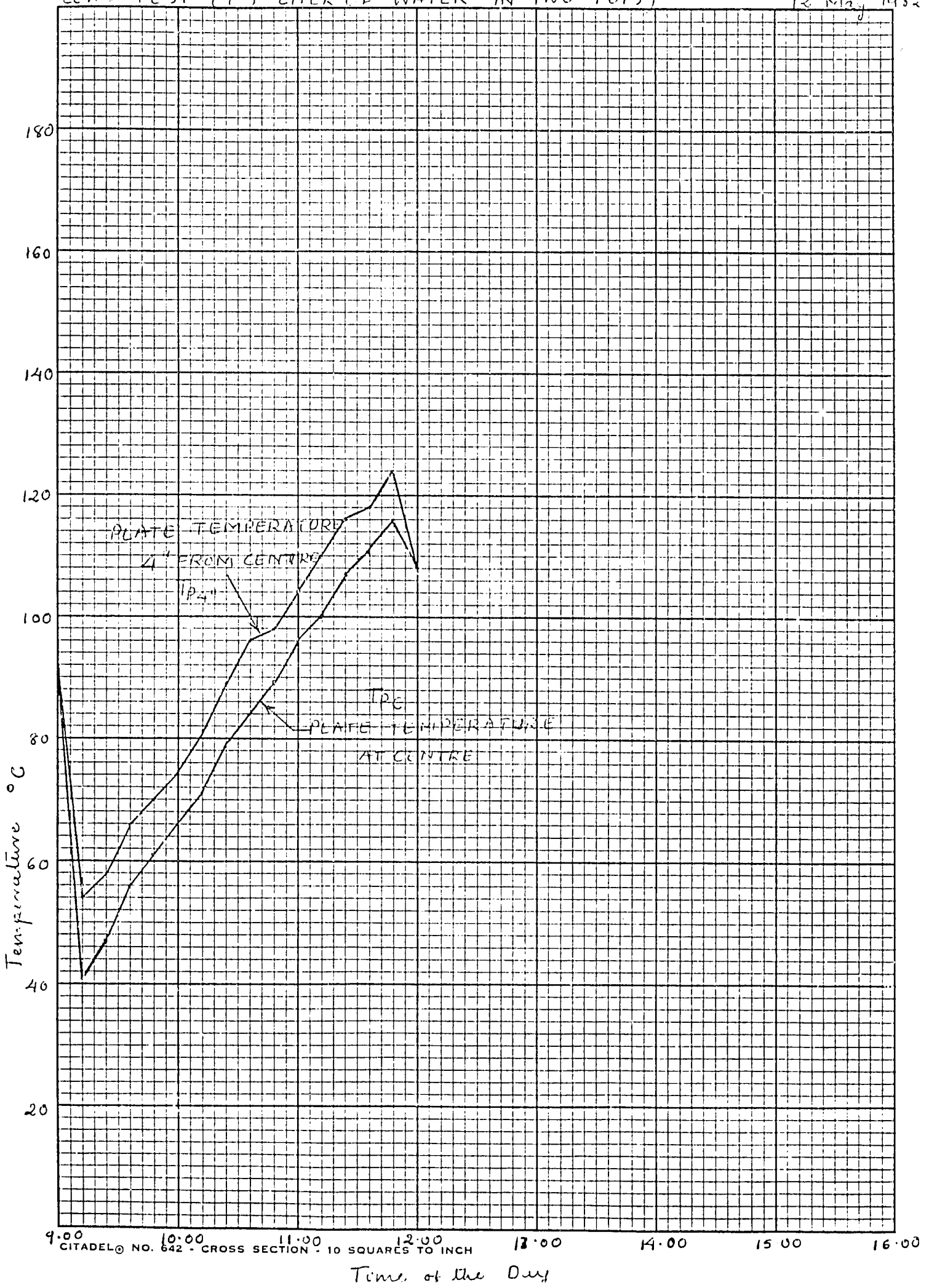
LOAD TEST

12 May 1952



CITADEL® NO. 642 - CROSS SECTION - 10 SQUARES TO INCH

LOAD TEST (1·5 LITER OF WATER IN TWO POTS) 12 May 1982



CITADEL® NO. 642 - CROSS SECTION - 10 SQUARES TO INCH