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# USE OF SOLAR ENERGY FOR THE DRYING OF CREPE RUBBER PART I. MODEL SOLAR COLLECTOR AND DRYING TOWER

*By*

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## SUMMARY

*A model flat plate solar collector having collector area of 4.86 $m^2$ coupled with a model crepe drying tower of dimensions: 2.4 m x 2.4 m x 3.6 m and total capacity of 200 kg has been installed. The performances of the collector in the context of drying of crepe laces has been evaluated. It has been found that the drying rate when using a solar collector is much higher than the drying rate at ambient temperature. The performance of this system has been used to validate the theoretical analysis of a collector, capable of handling the complete heating load in an actual drying tower.*

## INTRODUCTION

To maintain good quality in crepe rubber, it should be manufactured under well controlled conditions. As such, drying plays a very important role, since in-sufficient drying can cause mould growth and excessive temperatures can cause tackiness and discolouration due to oxidation. The best drying temperature is usually around 34°C.

Crepe rubber is usually dried as thin laces within specially built drying towers through which hot air is circulated. Lofts above factory floors are also sometimes used. Hot water to heat the air, circulates by thermosiphon action from the boiler to the radiators, which are installed at the lowest level of the tower.

It is estimated that rubber factories annually use in excess of 20,000 MT of firewood for heating purposes. The wood used is mainly rubber wood produced on each estate from trees lost by wind damage and disease and due to replanting programmes. In the present context, it is worthwhile investigating methods of conserving this valuable resource.

Tharmalingam (1980) investigated and popularised the use of electrical heating systems about 10 years ago, when electricity was very much cheaper than today. Electrical heating systems were found to be efficient and reliable but the present high cost of electricity and uncertain supply has meant that most estates with installations have discontinued its use.

The other freely available source is solar energy. The Rubber Research Institute (RRI) of Malaysia have carried out a number of experiments on this subject. Tharmalingam and Perera (unpublished data) started studies on solar drying of rubber at RRI Sri Lanka. A model collector and drying tower were constructed but only preliminary studies were done.

In this paper, the authors present the results of a series of experiments using a specially designed model collector and tower. A simple theoretical analysis is also done and some aspects of a basic collector *i.e.* the space between the roof and loft in a factory, are discussed.

## EXPERIMENTAL

Solar collectors fall into two broad categories *i.e.* concentrating collectors and flat plate collectors. In the former the rays of the sun are collected and concentrated optically by means of suitably arranged reflecting surfaces or lenses. The most common example is a parabolic trough type collector in which the rays are concentrated on to a pipe which runs along the focus of a reflecting parabolic mirror. In the flat plate type of collector, the sun's rays heat up a flat surface from which heat is gathered by a gas or liquid medium flowing through the collector.

Concentrating collectors are capable of producing very high temperatures in the range 100°C — 500°C or even higher. The maximum temperature required in drying towers is only about 34°C. Hence no purpose is served by using a concentrating collector. Flat plate collectors are capable of producing temperatures in the range 40 – 100°C. Since hot air is the medium which picks up the moisture from the crepe rubber, an air heater type solar collector is best used for these purposes.

The model collector installed at the RRISL, Ratmalana, consisted of a flat box in which the lower surface was matt black painted GI sheet (Fig. 1) (which acted as the absorber plate). The top surface consists of panes of window glass supported on a steel framework and sealed by a rubber compound. The sides of the collector were made of flat asbestos sheets. Heat loss from the absorber plate to the ground is prevented by a layer of insulation. The total collection area was 4.86 $m^2$.

Air was blown through the collector by means of a small axial flow fan, the speed of which was controlled by a regulator. Air from the collector is fed by a 15 cm drainage pipe into the model drying tower.

The drying tower dimensions were approximately 2.4m × 2.4m × 3.6m high and has a capacity of about 200 kg of laces. In the centre, a "brick pit" has been constructed to act as a container for gravel which was to be used for heat storage. Hot air from the collector was routed through the bed. Gravel of about 2.5 cm size to a depth of about 30 cm was used in these series of experiments. However, no attempt was made to measure the effectiveness of the bed as it was felt that further study of this type of heat storage bed was necessary.

## RESULTS

### Collector performance

Initially, the collector was tested on its own, disconnected from the drying tower. Air inlet and outlet temperatures and inlet air flow rates were monitored over periods of about 8—9 hours. A typical inlet and outlet temperature vs. time curve is given in Fig.3 .

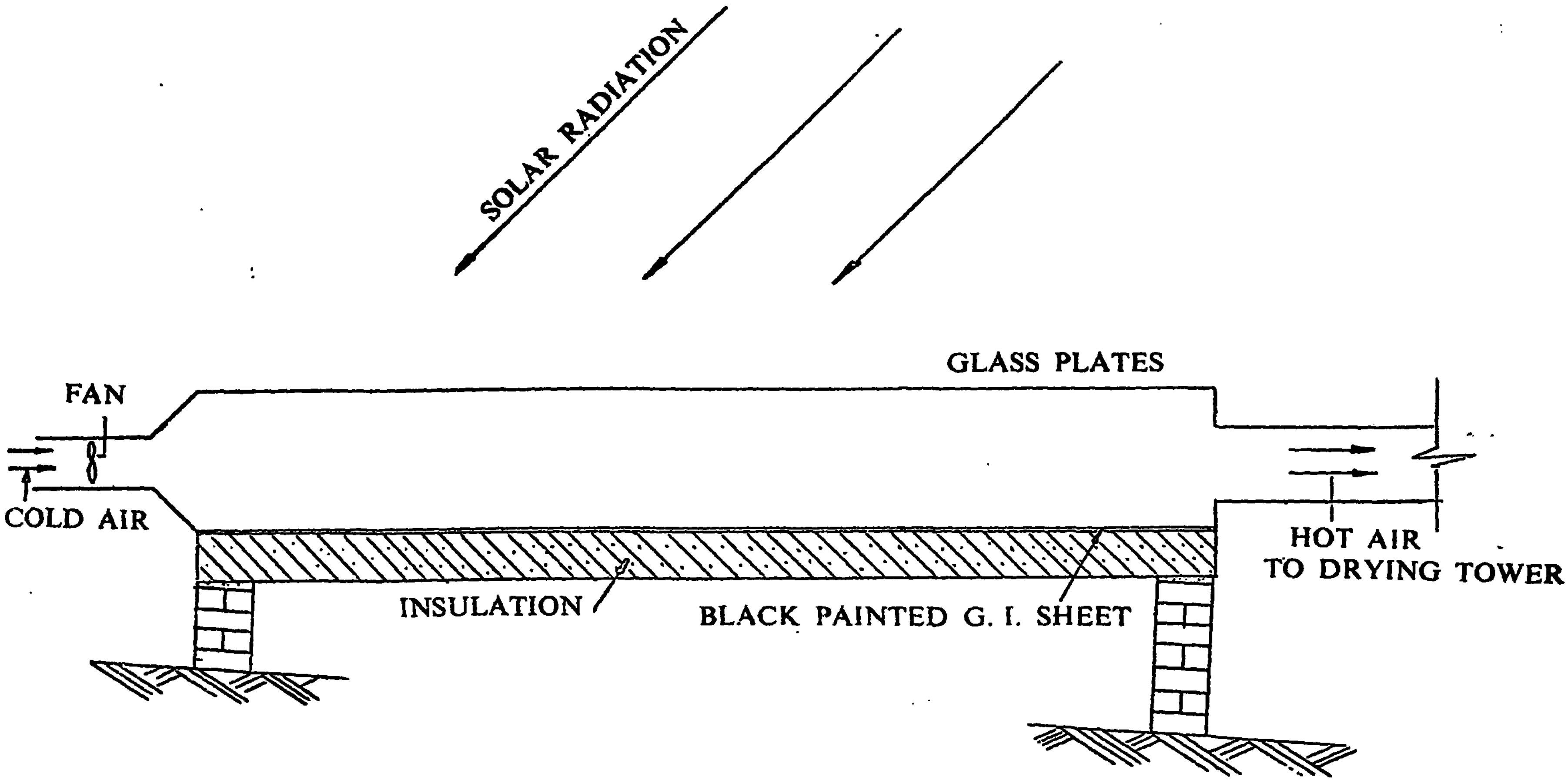



**Fig. 1: SOLAR COLLECTOR**

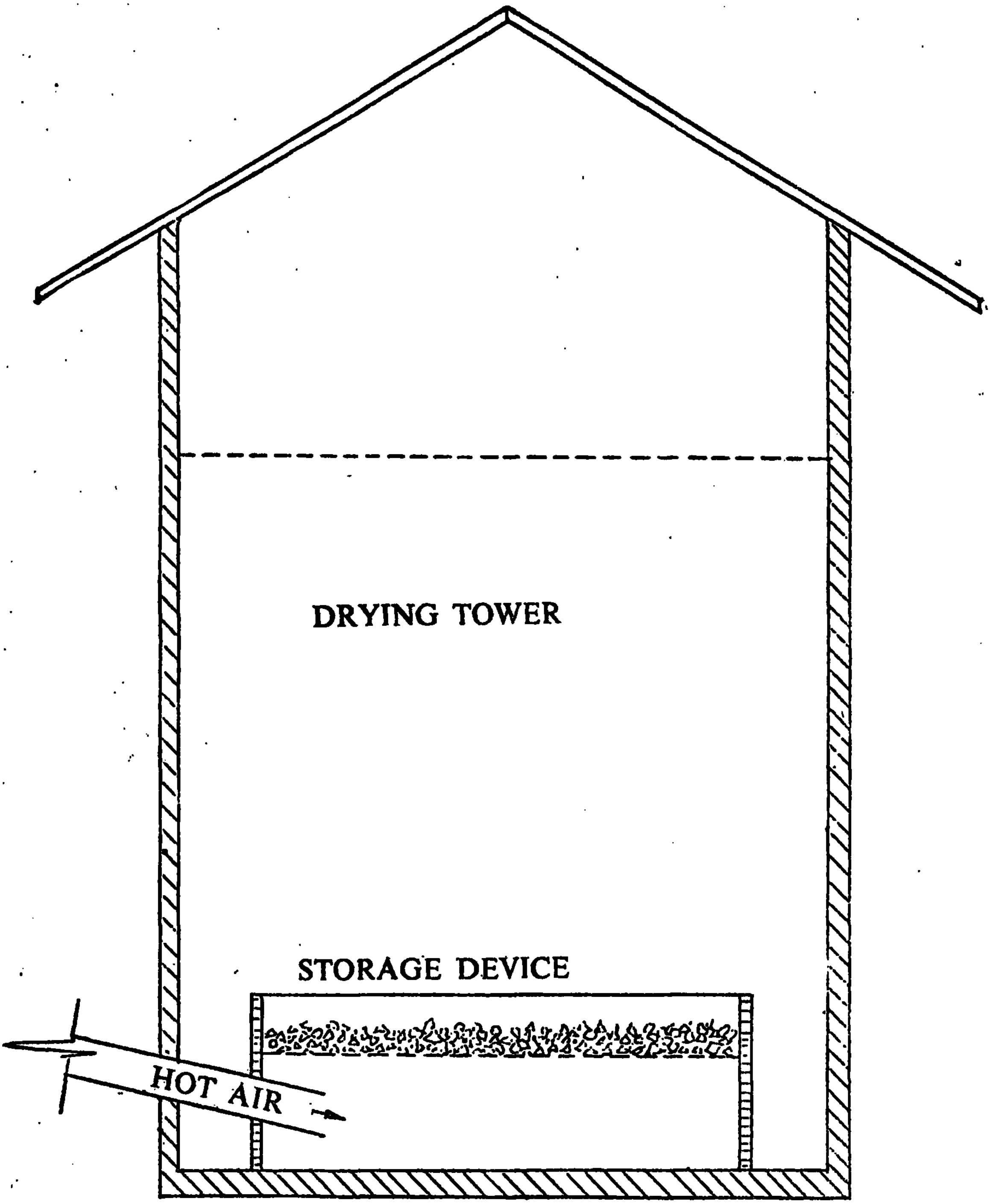



**Fig. 2: HOT AIR DISTRIBUTION AND STORAGE DEVICE**

The equation for temperature rise and efficiency in a flat plate air heater type solar collector is of the form

$$\Delta T = \frac{S}{U_L}\left[1 - e^{-\alpha/\upsilon}\right] \quad \text{------------(1)}$$

$$\eta = \frac{P\,C_P\,\upsilon}{U_L}\left[1 - e^{-\alpha/\upsilon}\right] \quad \text{------------(2)}$$

Where $\alpha = \frac{F^{1}\,U_L}{P\,C_P}$ ------------(3)

(See also Appendix I)

$\eta$ = Efficiency

S = Solar Energy received on to solar collector

$U_L$ = Overall heat loss coefficient from absorbing (*i.e.* air) to atmosphere

P = Density of air

$\upsilon$ = Air volume flow rate per unit surface area of solar collector

$F^{1}$ = Efficiency factor due to heat loss from absorber plate to atmosphere

$C_P$ = Specific heat of air

$\Delta T$ = Temperature rise across the collector

Replacing the various constants with values obtained empirically by investigators at the Malaysian Rubber Producers' Research Association (MRPRA) Matherell (1978).

$$\Delta T = 267\ R\ \left(1 - e^{-0.011/\upsilon}\right)$$

$$\eta = 267\ \upsilon C_P \left(1 - e^{-0.011/\upsilon}\right)$$

Where R is solar energy received and the units are kcal/cm²/sec. The units of $\upsilon$ and $C_P$ are $m^3$ / (sec. $m^2$) and kcal / ($m^3$. K. sec) respectively.

From Fig. 3, average temperature during the period of the experiment = 6.61°C.

Average temperature rise is estimated from :

$$\Delta T \text{ average} = \frac{\sum_{1-1}^{m} \Delta T}{n}$$

(the graph is divided into n equal intervals along the x axis)

| | | |
|---|---|---|
| Air flow rate | = | 10.4 $m^3$/min |
| ∴ Total heat pickup, by air | = | 10.36 × 0.24 × 6.61 × 600 × 1.1 |
| | = | 10,318 kcal |

The experiment was carried out in December 1983. Using an average insolation figure for this month of 0.0867 kcal/m/sec as provided by the Meteorological Department of Sri Lanka.

| | | |
|---|---|---|
| Total heat incident on the collector over a 10 hour period | = | 0.0867 × 3600 × 10 × 4.86 |
| | = | 15,169 kcals |
| ∴ Collector efficiency (from measured values) | = | $\frac{10,368}{15,169} = 68\%$ |
| Collector efficiency (from equation 5) | = | 61% |
| Collector temperature rise (from equation 4) | = | 6.1°C |

Hence the theoretical equations (4) and (5) give a reasonably good prediction of solar collector performance.

Drying tower performance

After the tests on the solar collector standing alone were completed, the collector was connected up to the drying tower and a further series of tests carried out with an empty tower.

Collector inlet air temperature, and tower internal temperature were monitored at various times during the course of a day, on several occasions. Different air flow rates were used. The results are shown in Figs. 4 to 8.

In all cases, it was found that tower internal temperature rose above ambient temperature only after 11.00 a.m. even though the collector supplies hot air from about 9.00 a.m. onwards. This can be attributed to the thermal inertia of the cooler air accumulated within the tower overnight, with which the incoming air from the collector mixes initially. This effect is not expected to arise in cases where overnight heating is carried out by means of stored heat or auxiliary heating systems.

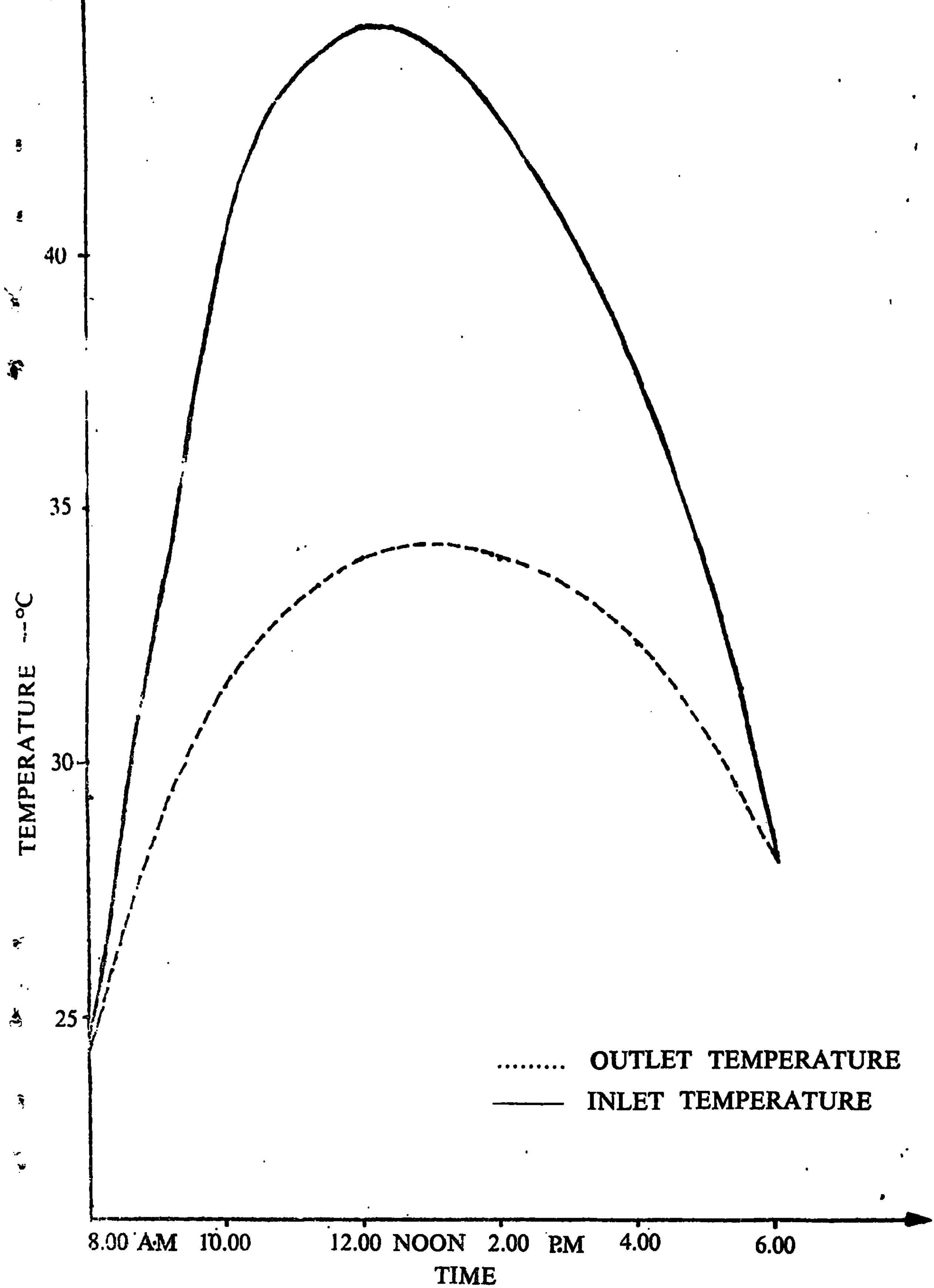



**Fig. 3: COLLECTOR PERFORMANCE**

Equally, the thermal inertia within the tower caused temperatures to remain above ambient even after the collector was shut down each day at 6.00 p.m. It was observed that elevated temperatures were maintained until about 7.00 — 7.30 p.m.

As mentioned earlier, no effort was made to quantify the effect of the stone bed in the tower. The maximum internal temperature obtained in the tower during these experiments was 37.7 °C.

Drying of crepe laces

After completing experiments, with the tower empty, some experiments were carried out with wet laces. In every case, the weight before drying was 50 kg.

Collector inlet air temperature, drying tower internal temperature and inlet and tower humidities were monitored. Moisture content was measured periodically by removing small samples and weighing immediately after removal and after drying in an electric oven. Tower inlet air flow rates were also measured.

The results of one set of experiments is presented in Fig. 9. A control experiment was also carried out using only ambient air. It can be seen that the drying rate is much higher when using the collector.

Drying rate with solar heated air = 0.28% per hour

Drying rate with ambient temperature air = 0.16% per hour

## DISCUSSION

There are spaces between the ceiling and roof in a rubber factory building. In many cases, it has been found that the air within the space reaches a fairly high temperature on bright sunny days. For example, at Padukka State Plantation Factory, maximum temperatures of about 34.4 °C have been recorded at 12 noon—1.00 p.m. on bright sunny days.

In fact, this space corresponds to a collector of the uninsulated type, whose major characteristic is a high heat loss coefficient. This would lead to rapid cooling at all times other than when there is direct sunlight on the roof.

The MRPRA has also investigated this type of collector and recommend it as a cheap alternative to a purpose built collector, especially where the space is already available.

Encouraging results have been obtained in preliminary experiments on the drying of crepe rubber using solar energy, without back up heating or significant heat storage.

Experiments with the model collector have also enabled validation of a theoretical analysis which can be used in collector design. Full size collectors which are capable of

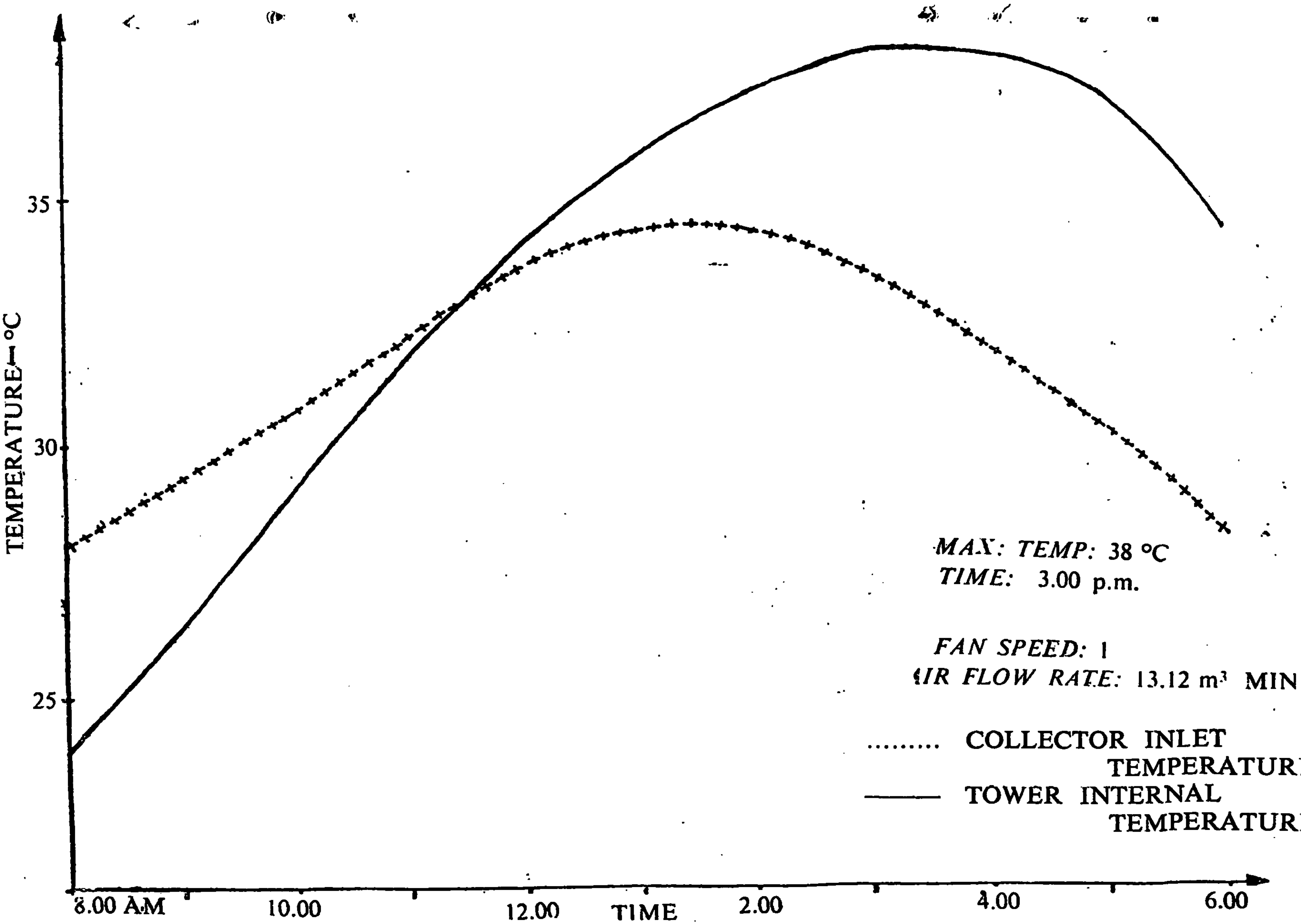



**Fig. 4: TOWER PERFORMANCE**

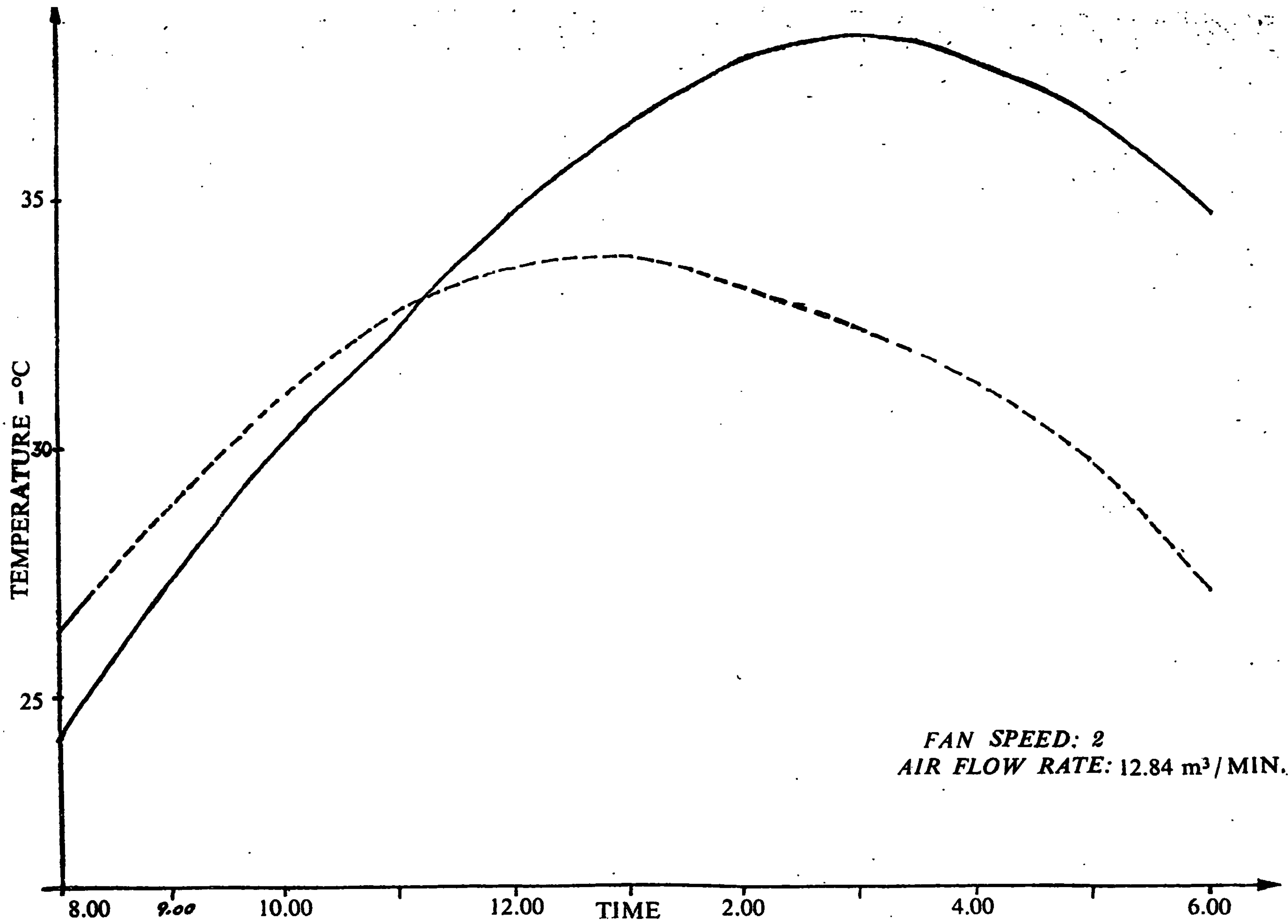
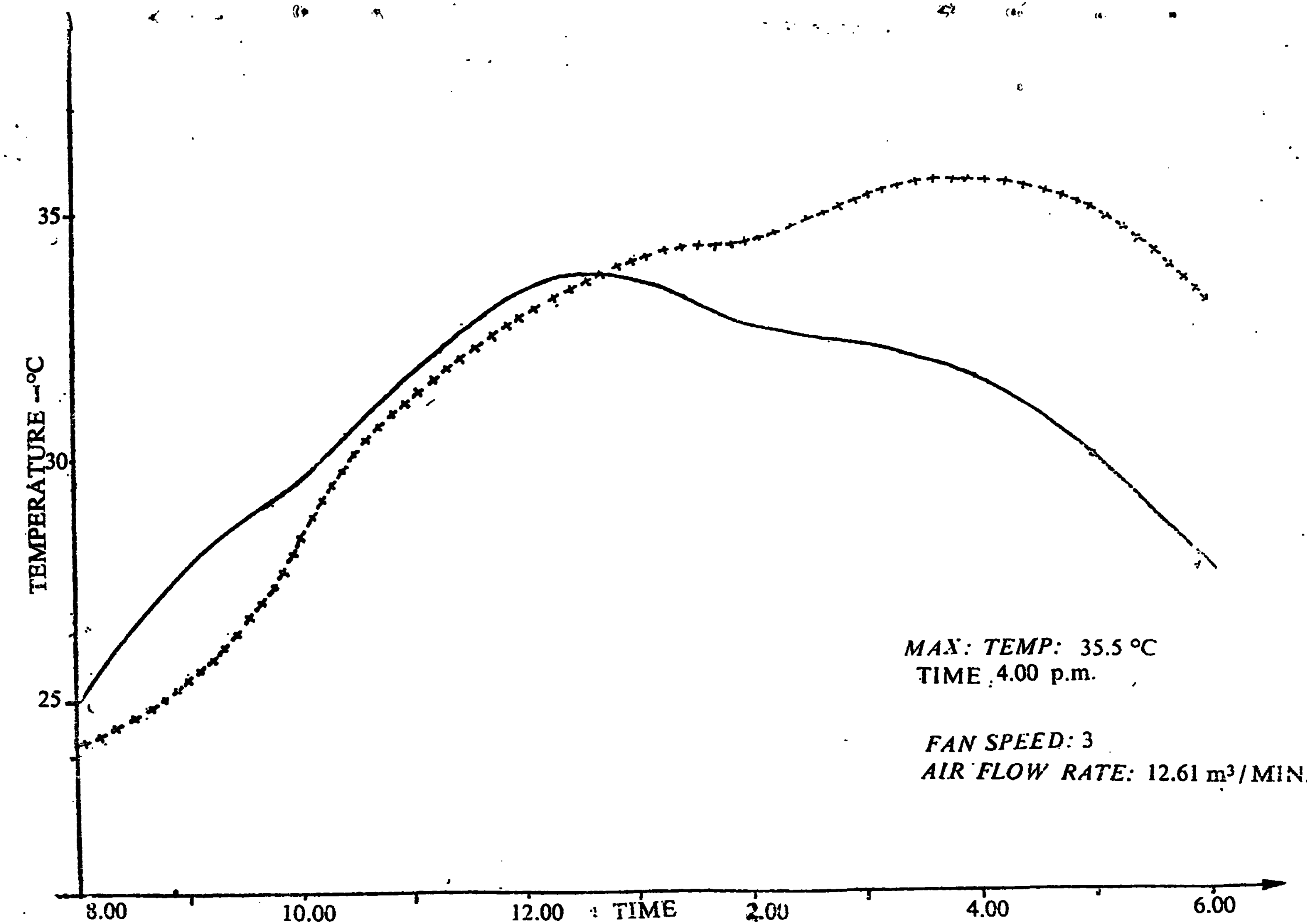



**Fig. 5: TOWER PERFORMANCE**



35
30
25
TEMPERATURE –°C
MAX: TEMP: 35.5 °C
TIME 4.00 p.m.
FAN SPEED: 3
AIR FLOW RATE: 12.61 m³/MIN.
8.00
10.00
12.00
TIME
2.00
4.00
6.00

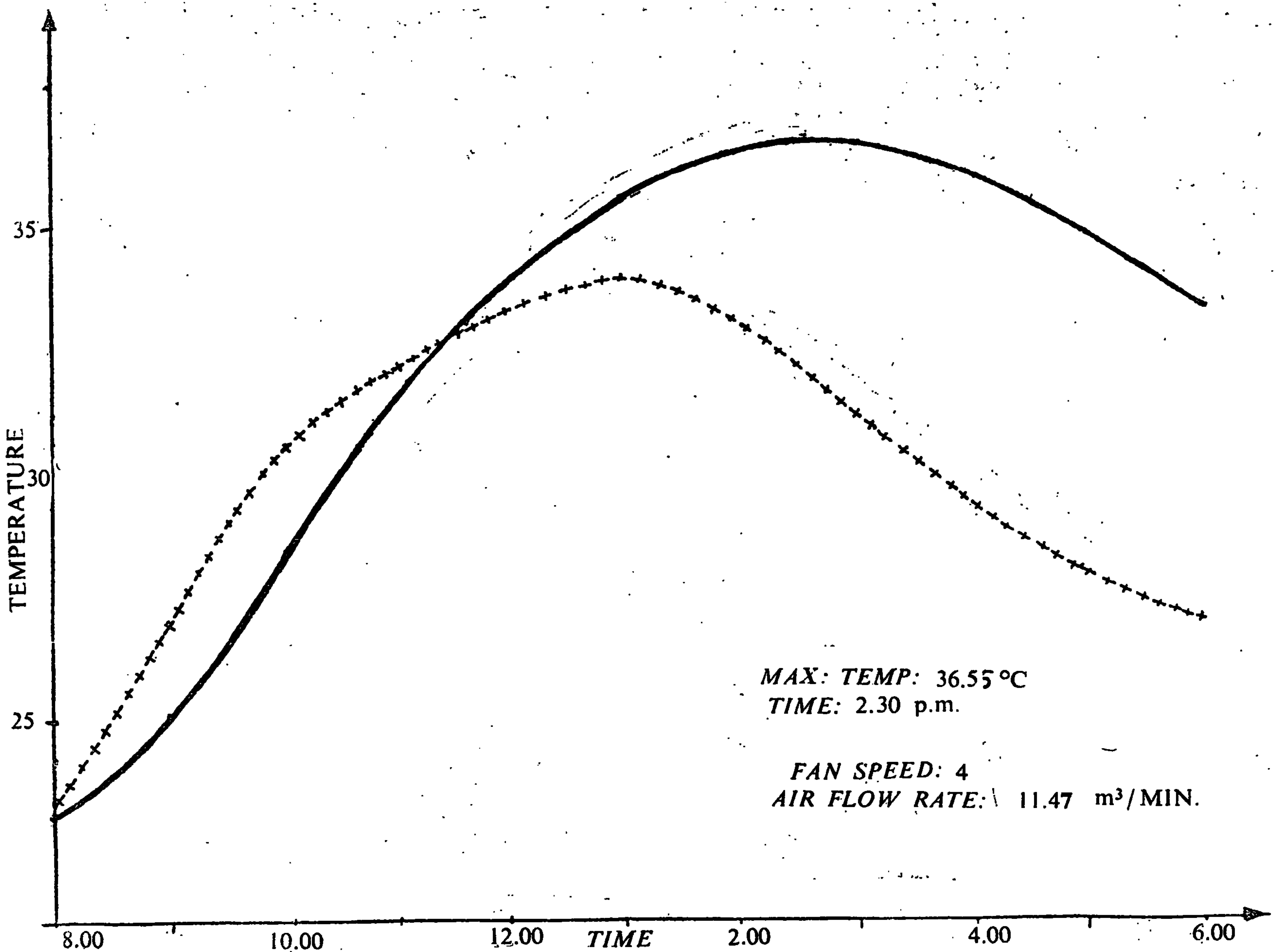



**Fig. 7: TOWER PERFORMANCE**

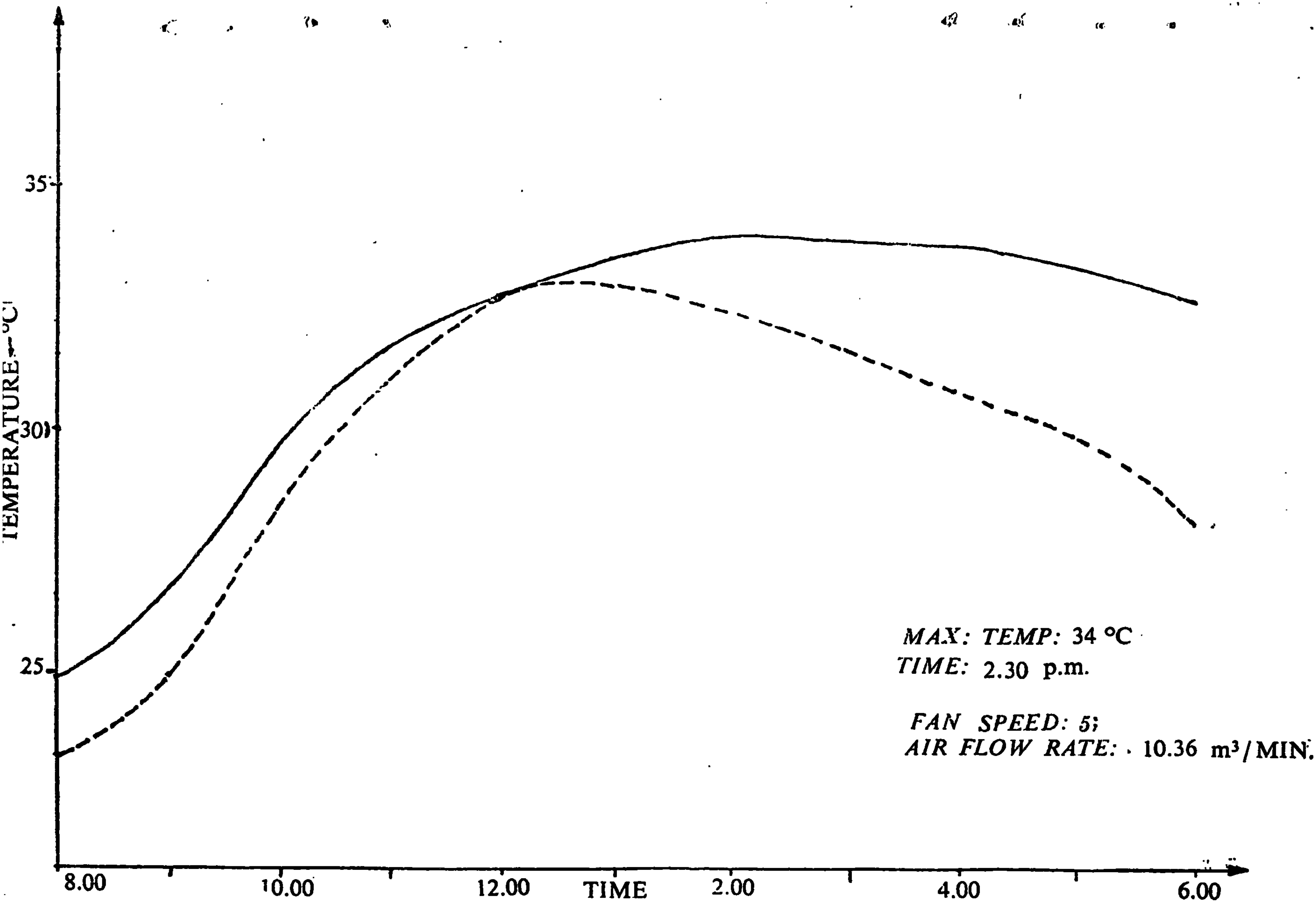



**Fig. 8: TOWER PERFORMANCE**

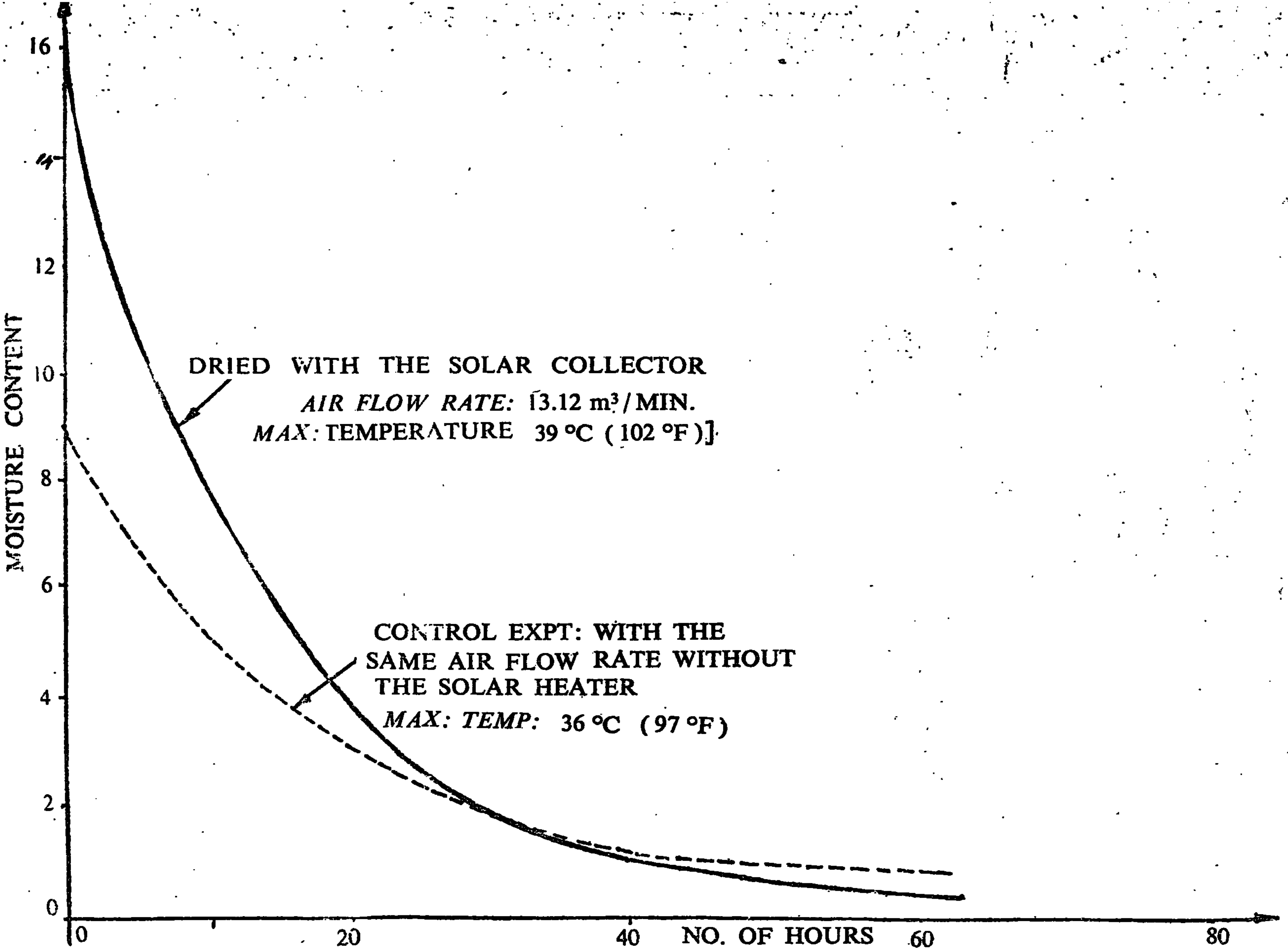


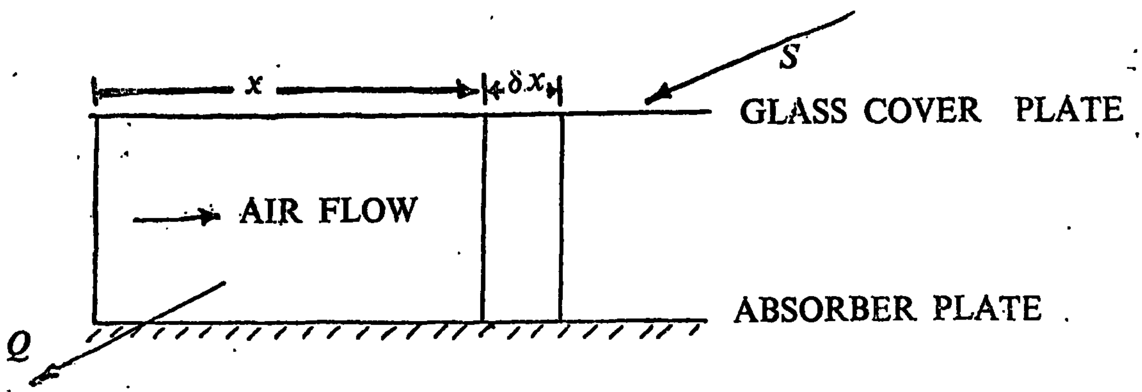

**Fig. 9: DRYING CURVE FOR CREPE LACES**

handling the complete heating load in an actual drying tower will be designed and fabricated for installation at RRISL, Dartonfield. The use of suitable heat storage methods and auxiliary heating for periods with little sunshine will also be investigated.

Roof loft type systems for the utilisation of solar energy will also be investigated in collaboration with a rubber estate where suitable space is already available.

## *Appendix I*

### Temperature rise and efficiency in a collector




In this type of collector, heat losses will take place by radiation from the absorber plate to the cover plate and by a combination of radiation and convection from the cover plate to the atmosphere. Heat loss will also take place from the fluid to the cover plate, by convection. Heat is gained by the fluid from the absorber plate by convection processes.

**Notation**

- $h_1$ = Convection heat transfer coefficient from fluid to the glass.
- $h_2$ = Convection heat transfer coefficient from absorber plate to fluid.
- $h_r$ = Radiative heat transfer coefficient from absorber plate to cover glass.
- $U_t$ = Combined convection and radiation coefficient from cover glass to atmosphere.
- $U_b$ = Heat loss coefficient from rear of absorber plate.
- S = Total insolation
- $q_u$ = Heat gain by the fluid in element
- $T_a$ = Ambient temperature
- $T_c$ = Temperature of cover glass
- $T_f$ = Temperature of fluid at x
- $T_{f,o}$ = Temperature of plate at the collectoı exit
- $T_p$ = Temperature of plate
- $T_{i,o}$ = Temperature of fluid at collector inlet.

From Energy Balance,

For the cover

$$(U_t + U_b)(T_a - T_c) + h_r(T_p - T_c) + h_1(T_f - T_c) = 0$$

For the fluid

$$h_1(T_c - T_f) + h_2(T_p - T_f) = q_u$$

For the absorber plate

$$S + h_2(T_f - T_p) + h_r(T_c - T_p) = 0$$

Ncte that the back loss is added to the cover loss coefficient to atmosphere, as otherwise the equations would become too unwieldy.

By manipulating, we obtain,

$$q_u = F^1 S + U_o(T_f - T_a)$$

Where;

$$F^1 = \frac{1}{1 \times \dfrac{h_r(U_t + U_b)}{(h_r h_1) + h_2(U_t + U_b) + (h_2 h_r) + (h_1 h_2)}}$$

$$U_o = \frac{U_t}{1 + \dfrac{U_t(h_2 + h_r)}{(h_1 h_2) + (h_1 h_r) + (h_2 h_r)}}$$

Or;

$$q_u = F^1 [S + U_L(T_f - T_a)] \quad \ldots\ldots\ldots\ldots\ldots\ldots$$

Where

$$U_L = \frac{(U_t + U_b)}{1 \times \dfrac{(U_t + U_b) b_2}{(h_1 h_2) + (h_1 h_r) + (h_r h_2)}}$$

*i.e.* the equation is now in a form where the total heat gain by the fluid is cortrolled by a factor $F^1$ $(O<F<1)$, called the collector efficiency factor and a heat loss coefficient which is related to the temperature difference between the fluid and ambient air.

Essentially, the factor $F^1$ arises because heat loss takes place not only from the fluid but also from the absorber plate, which is usually at a significantly higher temperature than the fluid.

Considering the fluid in the element $\delta$ x

$$q_u = \dot{m}C_p \frac{dT_f}{d_x} \delta_x = F^1 [ S - U_L (T_f - T_a) ] W. \delta_x.$$

where

$\dot{m}$ = mass flow rate

w = width of the collector

$C_p$ = specific heat of air

v = collector air flow per unit area

Therefore solving the first order differential equation and applying boundry conditions; we get:

$$T_i = T_a \text{ at } X = O$$

$$\triangle T = (T_{f,o} - T_a) = \frac{S}{U_L} \left[ 1 - e^{- F^1 U_L / PC_p V)} \right]$$

$$\text{Since} \quad \frac{\dot{m}}{WL} = PV$$

Therefore, collector efficiency, , is:

$$\eta = \frac{\dot{m}\, C_p\, (T_{f,o} - T_i)}{S\, W_L}$$

$$\eta = \frac{PC_p\, V}{U_L} \left[ 1 - e^{- F^1 U_L / PC_p\, V} \right]$$

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