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# DEVELOPMENT OF SOLAR-COLLECTOR TESTING PROCEDURES

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University of Florida, Gainesville, FL 32601 (USA)

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## SUMMARY

It has been felt that the procedure recommended by ASHRAE (no. 93-77) may not necessarily provide the useful information desired about a solar collector, especially in most of the developing countries where R & D workers, in general, do not have an access to the sophisticated instrumentation and operational facilities suggested by ASHRAE 93-77. The present project is an humble initiation in the direction of developing an alternative procedure for testing solar collectors which may provide the desired information characterizing the performance of the solar collector being tested. As it is not possible to arrive at an established procedure within the limited time available for project work, we hope that after going back to our respective countries a detailed extensive study can be made to develop the desired testing procedures.

## ACKNOWLEDGEMENTS

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## 1.0 INTRODUCTION:

A considerable attention is being paid, all over the world, to the development of efficient and cost effective solar energy collection devices. The parameters characterizing the performance of a typical solar collection device are the major detrimental factors as regards the performance of a solar collection system apart from the local insolation and environmental characteristics. Efforts have been made and are still continuing to develop testing procedures so as to characterize the performance of several types of solar collectors with different designs and different materials used. The most commonly followed procedure is that recommended by ASHRAE 93-77. A brief description of the same is given below:

## 1.1 ASHRAE 93-77 Testing Procedure:

The ASHRAE standard 93-77 recommends test methods for determining the thermal performance of solar energy collector modules which heat fluids for use in thermal systems (1). The procedure is recommended to test nonconcentrating as well as concentrating collectors both for outdoor and simulated indoor testing so as to determine their steady state and/or quasi state thermal performance. Moreover, it is also recommended to determine the collector time constant and the variation of collector efficiency with changing angle of incidence using the described procedure. ASHRAE 93-77 standard puts some specific test requirements (including preconditioning of the solar collector) on collector size, test site, mounting type, collector orientation, time of the day, integrated average irradiation incident on the plane of the collector, ambient temperature, physical and chemical properties of the heat transfer fluid and finally the measuring and recording instruments. The thermal performance of a solar collector is then determined by experimentally measuring the rate of incident solar radiation onto the solar collector and the useful energy collected by the heat transfer fluid as it passes through the collector, all under steady state or quasi state conditions.

The energy balance of a flat plate solar collector operating under steady state conditions can be written as (1)

$$\frac{q_u}{A_a} = I_t (\tau\alpha)_e - U_L (\bar{t}_p - t_a) \quad \text{------ (1)}$$

As the useful energy given by eq.(1) is transferred to the working fluid by raising its temperature; it may also be expressed as

$$\frac{q_u}{A_a} = \frac{\dot{m}}{A_a} C_p (t_o - t_i) \quad \text{------ (2)}$$

In order to avoid the necessity for determining the average temperature of the absorber surface, it is preferred to write the energy balance equation in the following alternative form:

$$\frac{q_u}{A_a} = F_R \left[ I_t (\tau\alpha)_e - U_L (t_i - t_a) \right] = \frac{\dot{m} C_p}{A_a} (t_o - t_i) \quad \text{------ (3)}$$

Using eq.(3), the efficiency of the flat plate solar collector which is defined as the ratio of the useful energy collected to the total energy incident on the plane of the collector may be written as:

$$\eta = \frac{q_u}{I_t A_a} = F_R \left[ (\tau\alpha)_e - \frac{U_L (t_i - t_a)}{I_t} \right] = \frac{\dot{m} C_p (t_o - t_i)}{I_t A_a} \quad \text{------ (4)}$$

It may be seen from eq.(4) that if the efficiency ($\eta$) is plotted against $\left( \frac{t_i - t_a}{I_t} \right)$, a straight line will result the slope of which will be equal to $F_R U_L$ and whose y intercept will be equal to $F_R (\tau\alpha)_e$. Fig. 1 shows the results of a test conducted outdoors following the procedure recommended by ASHRAE 93-77 (From Ref 1).

## 1.2 Shortcomings of the ASHRAE Standard 93-77

(i) ASHRAE 93-77 can not be used to test and represent performance of those solar collectors for which the inlet temperature is the same as the ambient temperature. For example, in case of large solar crop dryers the ambient air is blown inside the dryer using a fan or a blower. In such a case, the ordinate $\left(\frac{t_i - t_a}{I_t}\right)$ of fig.1 is always zero and one is always operating at the origin of the coordinate system.

(ii) In pradical applications of a flat plate solar collector, the operating temperatures are usually much more higher than the ambient temperature However, for testing purposes using water as heat transfer fluid, in most of the tropical locations the ambient temperature will, in general, be higher than the inlet water temperature, unless an automatically controlled preheating system is used. In such cases $\left(\frac{T_i - T_a}{I_t}\right)$ will be a negative quantity. Apparently, ASHRAE 93-77 does not seem to be allowing for such a situation and thus prescribing the use of more automation and/or simulated testing procedures both of which may be difficult to follow for the developing countries where such facilities are not commonly available.

(iii) Fig.1 obtained by following ASHRAE 93-77, as such, does not provide information about the amount of energy collected by the collector. ASHRAE 93-77 recommends that the tests should be made during relatively clearer days, however, a flat plate collector has to operate in all kinds of weather conditions and therefore the testing made in accordance with the above procedure may not necessarily provide useful information for practical operating conditions.

(iv) In actual practice, $U_L$ varies with the operating temperature and also the effective transmittance absorptance product $(\tau\alpha)_e$ varies with incidence angle and therefore a straight line as shown in Fig (1) may not always be obtained experimentally.

(v) Fig (1) does not provide any information about the operating temperatures as the curve does not say anything about it.

(vi) The constraints imposed by ASHRAE 93-77 on the positioning and site of test (e.g. ground reflectivity, no shading etc) of a solar

collector may not always be taken care of at practical installations. Therefore, a test performed under ideal conditions as recommended by ASHRAE 93-77 may not be meaningful in its real sense.

(vii) Another major constraint in the ASHRAE 93-77 testing procedure is on the ambient temperature. It is recommended that the range of ambient temperatures for all reported points comprising the efficiency curve should be less than 30°c. However, at several locations in the world, the ambient temperature is higher than 30°c during a considerable portion of the year thus limiting not only the applicabilibility of the ASHRAE 93-77 outdoor testing procedure for those locations, but also the meaningfulness of the results of the tests conducted under simulated conditions to draw conclusions about the performance of the collector practically put to work on such locations.

(viii) Finally, ASHRAE 93-77 recommends the use of those measuring and recording instruments which are sophisticated and hence very expensive. Therefore, most of the test facilities established (or being established) in developing countries can not have an easy access to them with desired degree of accuracy. This also necessitates the development of a simple alternative testing procedure which may allow the use of locally manufactured equipments and still provide meaningful data.

## 2. DEVELOPMENT OF AN ALTERNATIVE TESTING PROCEDURE

With an appreciation to the efforts that has been made so far by National Bureau of Standards and ASHRAE in bringing out the present test procedure (ASHRAE 93-77) we feel that it is too early for us to claim having established an alternative test procedure. However, with the problems mentioned above in section 1.2 in mind, we strongly feel that there is an immediate need for the development of a suitable simple test procedure to provide more meaningful data.

The primary information which one would like to know about a typical solar collector is the amount of energy collected in different weather conditions. For example, it will be useful if the amounts of energy collected on a clear day, on a semicloudy day and on a

cloudy day are known for a certain set of values of mass flow rate and inlet and ambient temperatures. Then, with the use of a reliable long term radiation data, a good estimate of the total energy collected throughout the year can be made. If $E_1$, $E_2$ and $E_3$ are the total energies collected by a solar collector on a clear, a semi cloudy and a cloudy day respectively, then the total yearly energy collected by the solar collector may be expressed as

$$E_{yearly} = n_1 E_1 + n_2 E_2 + n_3 E_3 \quad \text{- - - - (5)}$$

where $n_1$, $n_2$ and $n_3$ are the number of clear, semi-cloudy and cloudy days during the year respectively and can be determined by the study of long term radiation data of the location. The values of $E_1$, $E_2$ and $E_3$ can be calculated by measuring the inlet and outlet temperatures of the heat transfer fluid (water) with a known mass flow rate passing through the collector.

The transient behaviour of a solar collector can be studied by following a procedure similar to that recommended by ASHRAE 93-77.

As regards generating a curve similar to Fig (1) which is recommended by ASHRAE 93-77 so as to determine some of the parameters characterizing the optical and thermal performance of the solar collectors (eg $F_R$, $U_L$ and $(\tau\alpha)_e$), it seems that instead of using $\left(\frac{T_i - T_a}{I_t}\right)$ as an ordinate it may be more meaningful to use $\left(\frac{\bar{T}_w - T_a}{I_t}\right)$ as the ordinate where $\bar{T}_w \left(= \frac{T_i + T_o}{2}\right)$ is the average water temperature. However, the implications of using such a curve are still debatable and further studies in this direction are desirable.

## 3. TEST PROCEDURE FOLLOWED:

A locally available flat plate solar collector (aperture area=0.88 $m^2$) was used for the testing purpose. In order to maintain a steady fluid flow into the collector a simple arrangement

consisting of a bucket with a continuous overflow facility providing a constant head was used. The mass flow rate was determined by measuring the mass of the outgoing water in a certain period of time. The inlet, outlet and ambient temperatures were measured using thermocouples and recorders and the incident solar radiation on the collector plane was measured by recording the output of an Eppley pyranometer mounted on the plane of the collector. The measurements for three different types of days (clear, semi cloudy and cloudy) were made starting at 10.AM till 3.00 P.M.

The response time of the collector is calculated by measuring the variation in the outlet temperature of the water after suddently shading the collector so that it does not receive any radiation.

## RESULTS AND DISCUSSION :

Figs 2, 3 and 4 show the variation of insolation on the collector plane with the local time at Gainesville, for a clear, semi cloudy and cloudy day respectively. The total energy received by the collector during the test period is given by the area under the respective curves. The variation of useful energy collected with the local time for a more or less constant inlet temperature is shown in Figs 5, 6 and 7 for three different types of days respectively. The area under these curves may approximately give the total useful energy collected during the test period. Table(1) gives these numbers and also the overall efficiencies of the collector which are calculated by dividing the useful energy collected by the incident energy for each day. It should be noted that the values given in Table(1) may not necessarily represent the true picture in the sense that the test were not continued for complete sunshine duration. However a similar may be followed to obtain more realistic figures.

Fig. 8 shows the variation in the outlet temperature after a sudden shading is applied to the collector aperture. As per definition, the time constant of the collector comes out to be 171 seconds

Fig. 9 shows the efficiency curve obtained by following ASHRAE 93-77. It may be seen that as throughout the testing period the ambient temperature was higher than the inlet water temperature, a negative value for the ordinate $\left(\frac{T_i - T_a}{I_t}\right)$ is obtained.

An alternative way of representing this variation is shown in Fig (10) where ~~the~~ $\left(\frac{\bar{T}_w - T_a}{I_t}\right)$ is used as an ordinate instead of $\left(\frac{T_i - T_a}{I_t}\right)$. Apparently it seems that the problem faced in Fig. 9 is avoided to some extent, however, further research is required to develop a proper method of this kind of representation.

## 5. CONCLUDING REMARKS

The present project is just the beginning of our efforts in the direction of developing an alternative procedure for testing solar collectors. It is, however, evident that ASHRAE 93-77 may not always provide a meaningful information and further studies in this direction are desirable.

## 6.0 REFERENCES

1. ASHRAE standard 93-77 'Methods of testing to determine the thermal performance of solar collectors'. The Americal society of Heating, Refrigerating and Air Conditioning Engineers Inc, 345 East 47th street, New York, N.Y. 10017, USA (1977)

# NOMENCLATURE

$A_a$: Transparent frontal area of the collector ($m^2$)

$C_p$: specific heat of the heat transfer fluid (J/Kg °C)

$E_1$: Energy collected by the collector on a clear day (J)

$E_2$: Energy collected by the collector on a semi-cloudy day (J)

$E_3$: Energy collected by the collector on a cloudy day (J)

$E_{yearly}$: Total energy collected by the collector in a year (J)

$F_R$: Heat removal factor

$I_t$: Total solar radiation incident upon the aperture plane of the collector ($W/m^2$)

$\dot{m}$ = mass flow rate of the heat transfer fluid (Kg/sec)

$n_1$: number of clear days in an average year

$n_2$: number of semi cloudy days in an average year.

$n_3$: number of cloudy days in an average year.

$q_u$: rate of useful energy extraction from the collector (Watts)

$t_a$: ambient air temperature (°C)

$t_i$: inlet temperature of the heat transfer fluid (°C)

$t_o$: outlet temperature of the heat transfer fluid (°C)

$t_{o,initial}$: temperature of the heat transfer fluid leaving the collector at the begining of a specified time period (°C)

$t_{o,T}$: temperature of the heat transfer fluid leaving the collector at a specified time. (°C)

$\bar{t}_p$: average temperature of the absorber plate (°C)

$\bar{t}_w$: average water temperature (°C)

$U_L$: Overall heat transfer coefficient ($W/m^2$ °C)

$(\tau\alpha)_e$: effective transmittance absorptance product

$\eta$: efficiency of collection of flat plate solar collector.

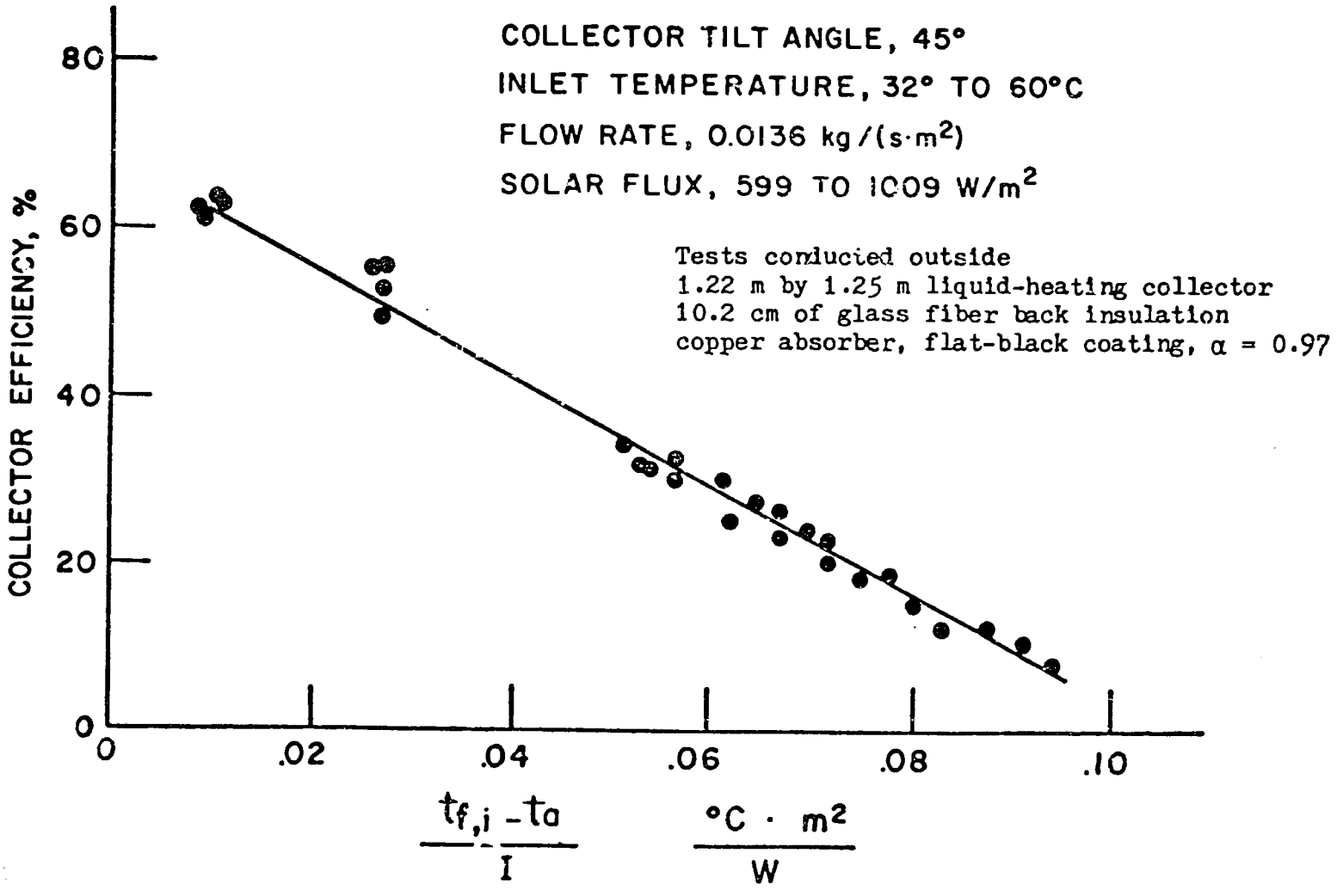
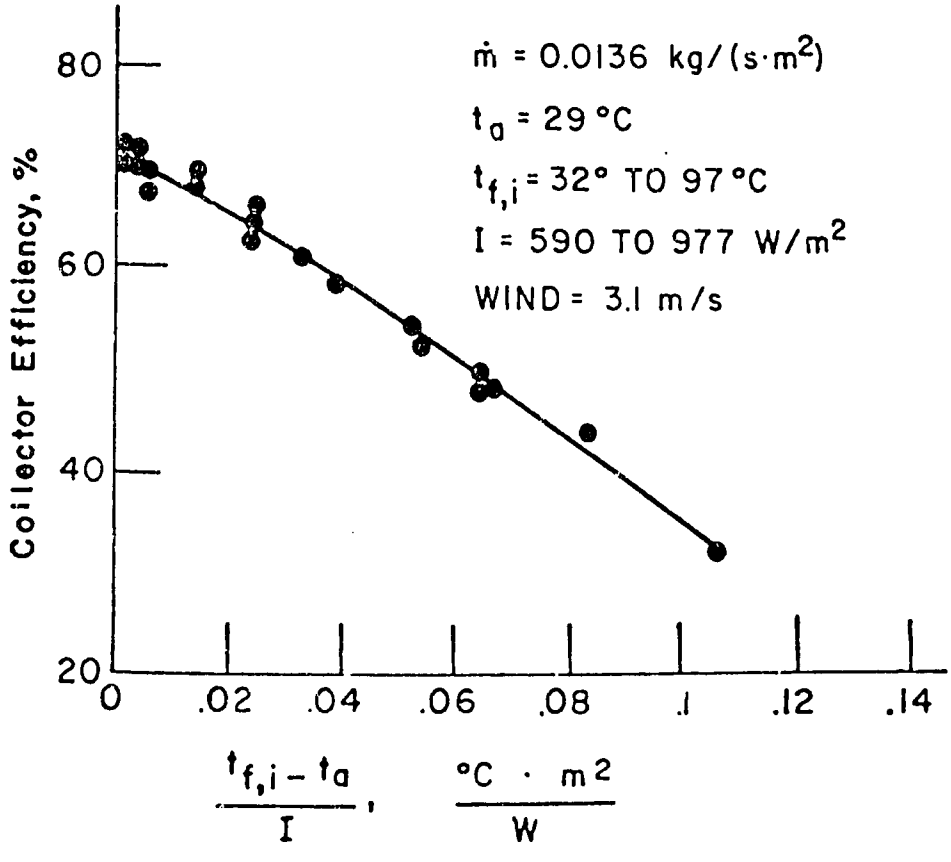



Fig. 1 (From Ref. 1)

14w

Tests conducted inside using a solar simulator
1.22 m by 1.22 m liquid-heating collector
insulation unspecified
aluminum abscrber, black-nickel selective coating, $\alpha = 0.95$



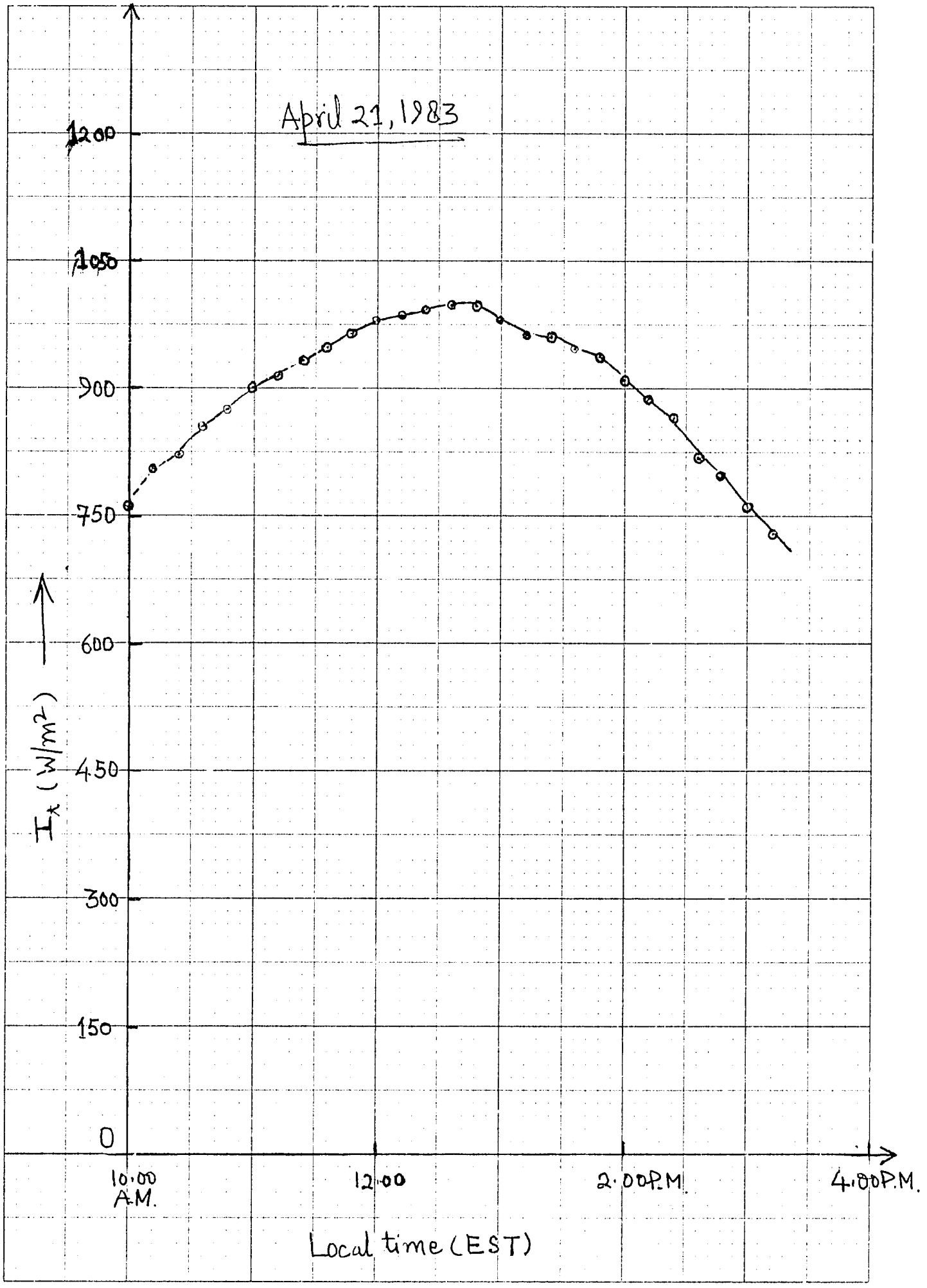



Fig 2

46 0780
K+E 10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

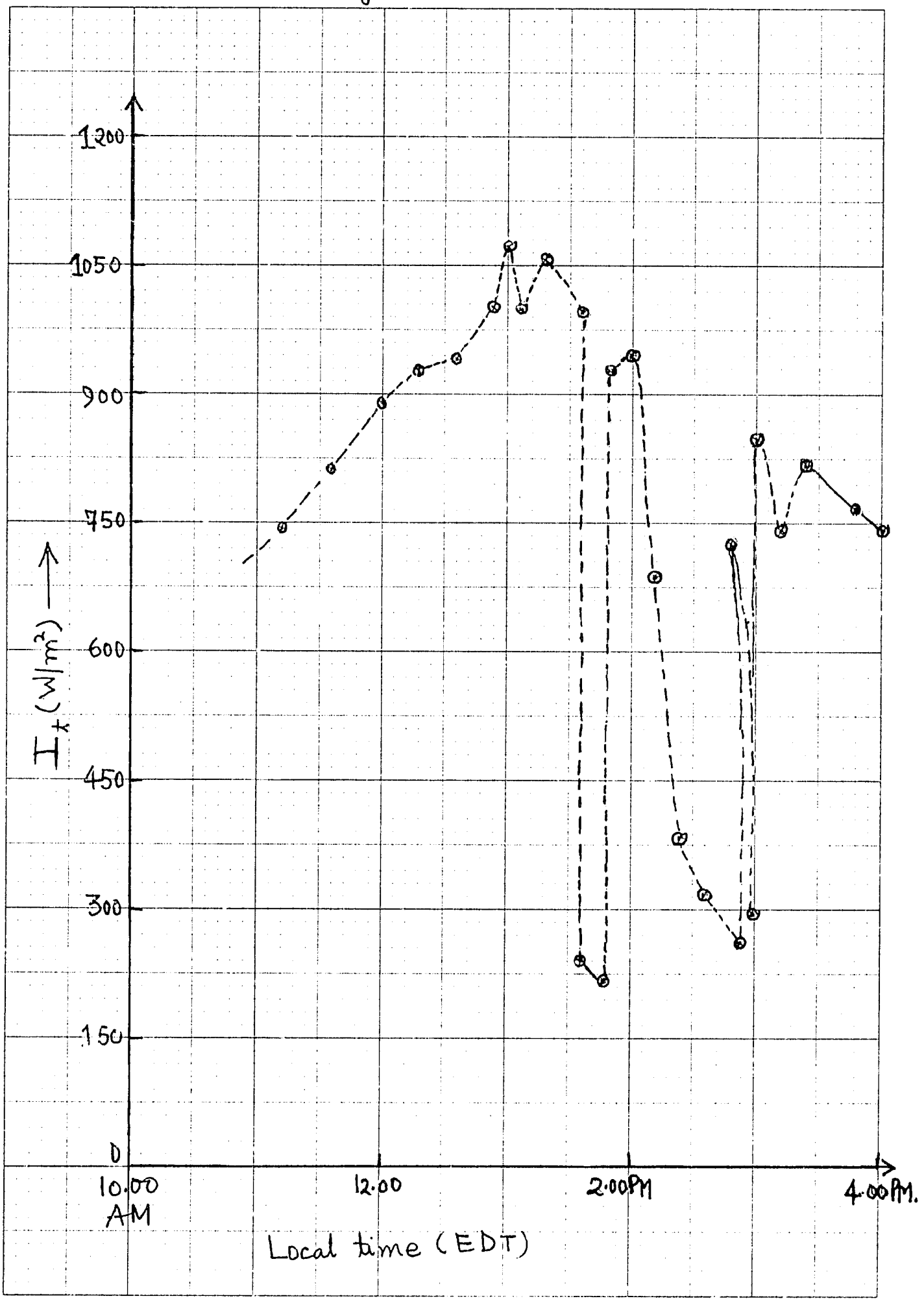



Fig 3

46 0780
K+E 10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

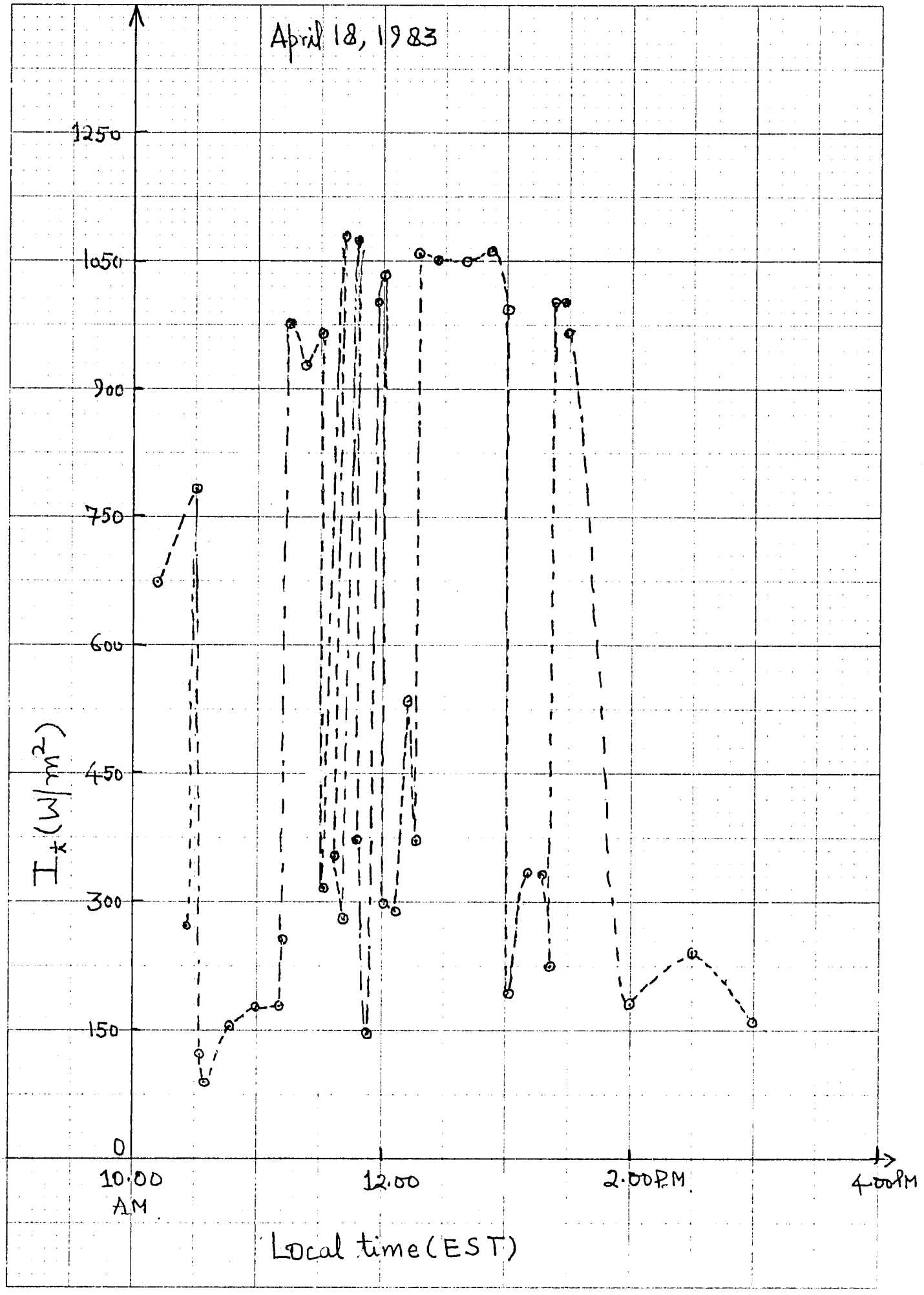



Fig 4.

46 0780
10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

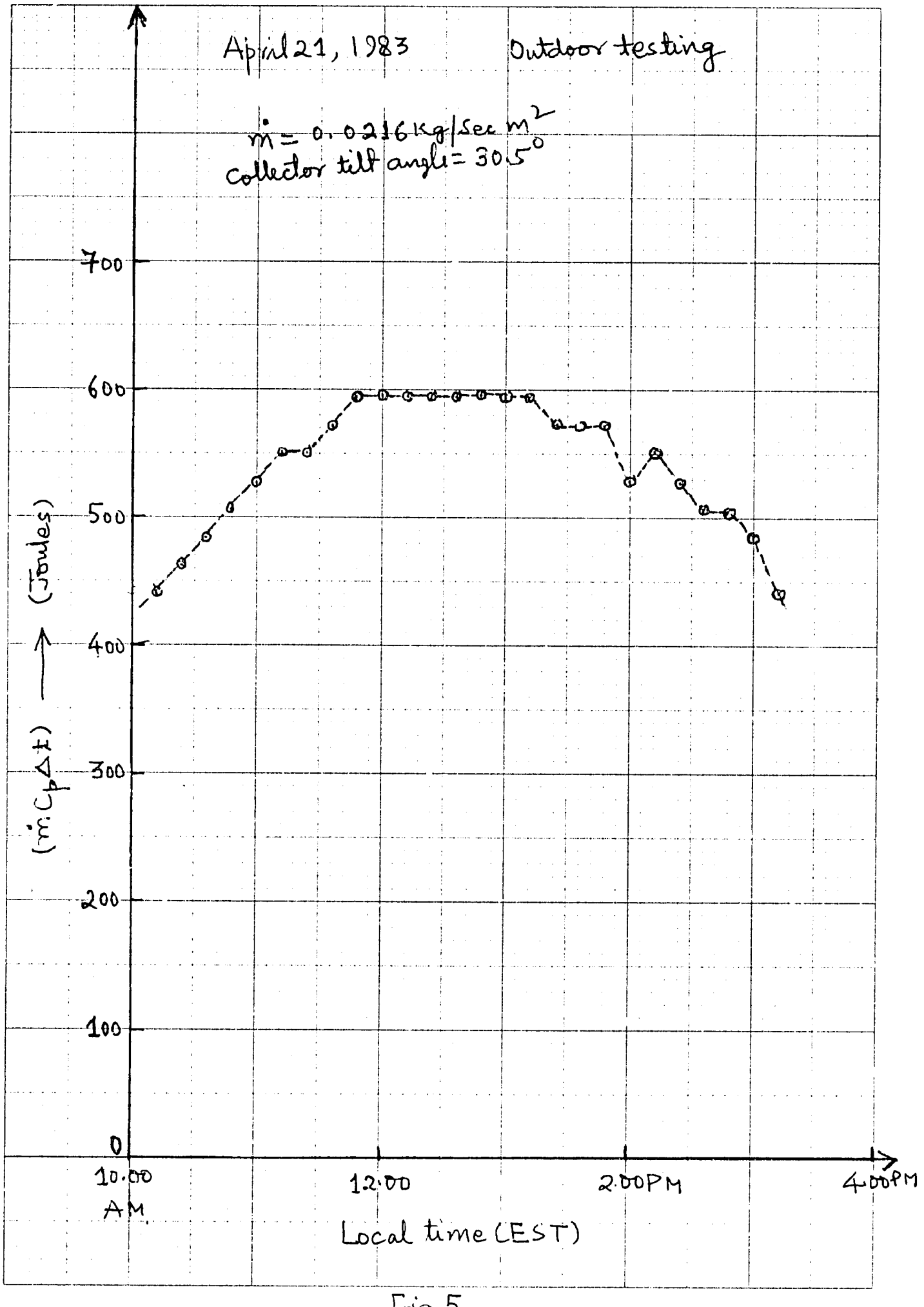



Fig 5

46 0780
10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

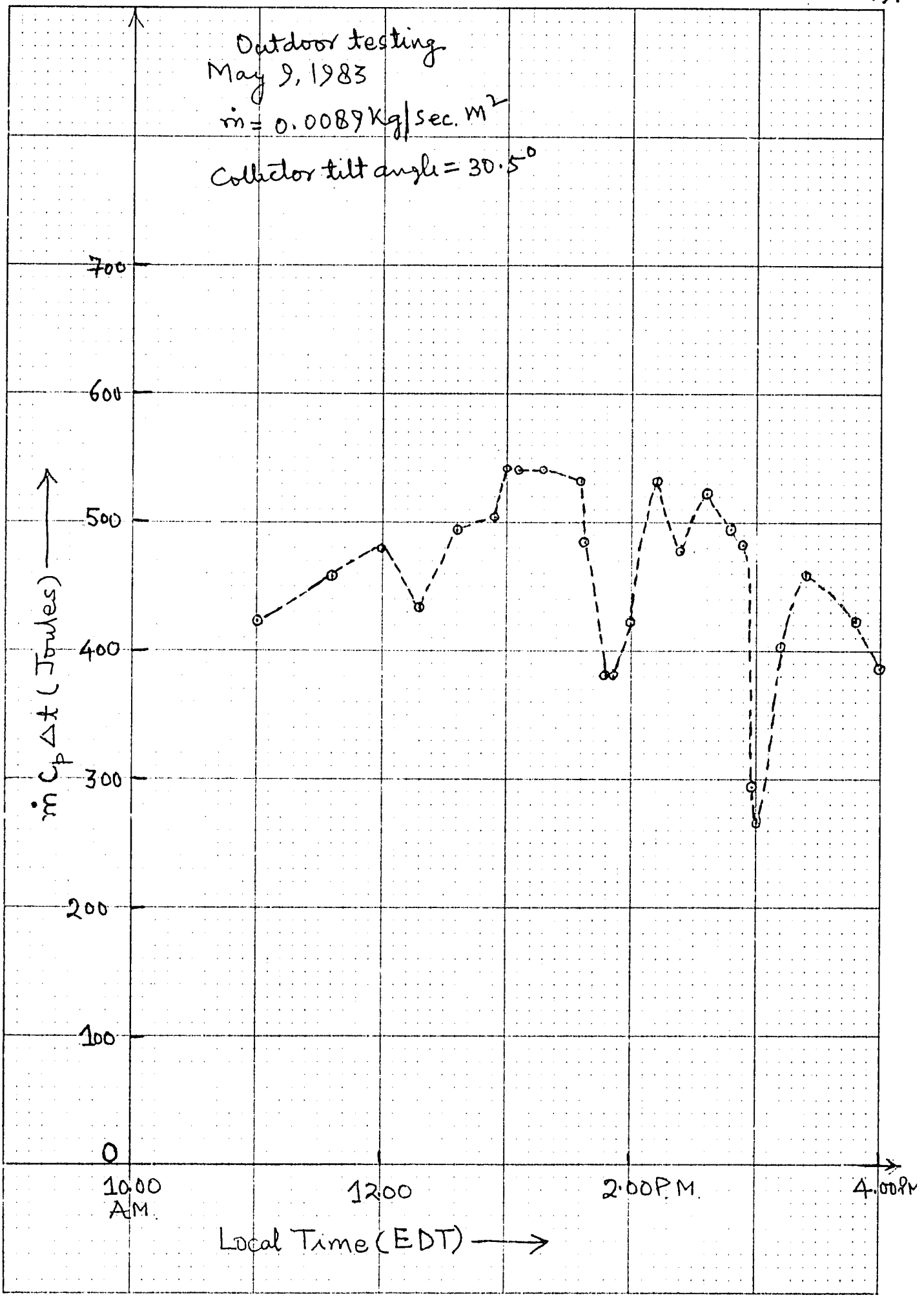

Outdoor testing
May 9, 1983
$\dot{m} = 0.0089$ Kg/sec. $m^2$
Collector tilt angle = 30.5°
700
600
500
400
300
200
100
0
$\dot{m} C_p \Delta t$ (Joules)
10:00 AM
12:00
2:00 P.M.
4:00 PM
Local Time (EDT)

Fig. 6

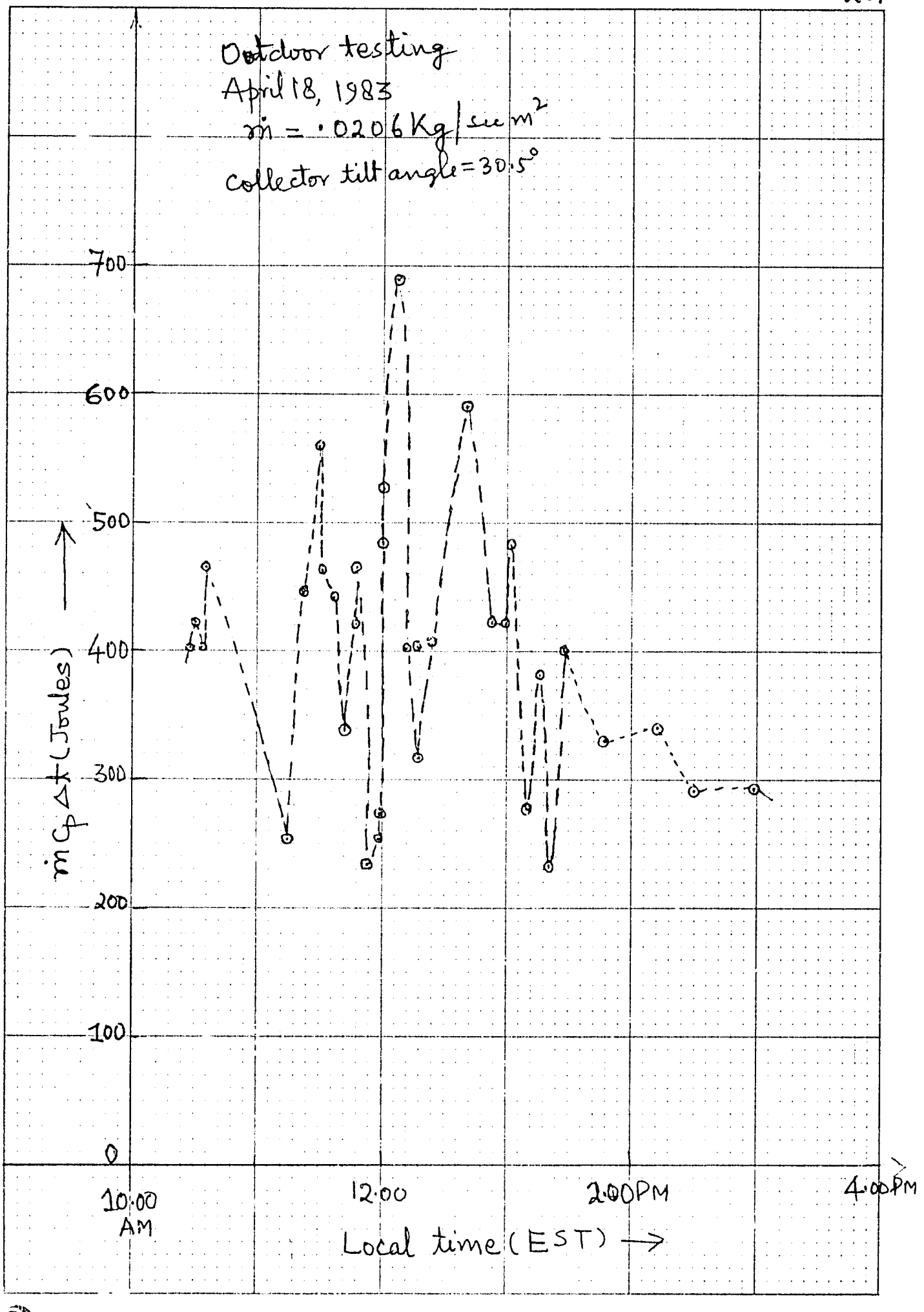

Outdoor testing
April 18, 1983
ṁ = .0206 Kg/sec m²
collector tilt angle = 30.5°
700
600
500
400
300
200
100
0
ṁ Cp Δt (Joules)
10:00 AM
12:00
2:00PM
4:00PM
Local time (EST) →

Fig. 7

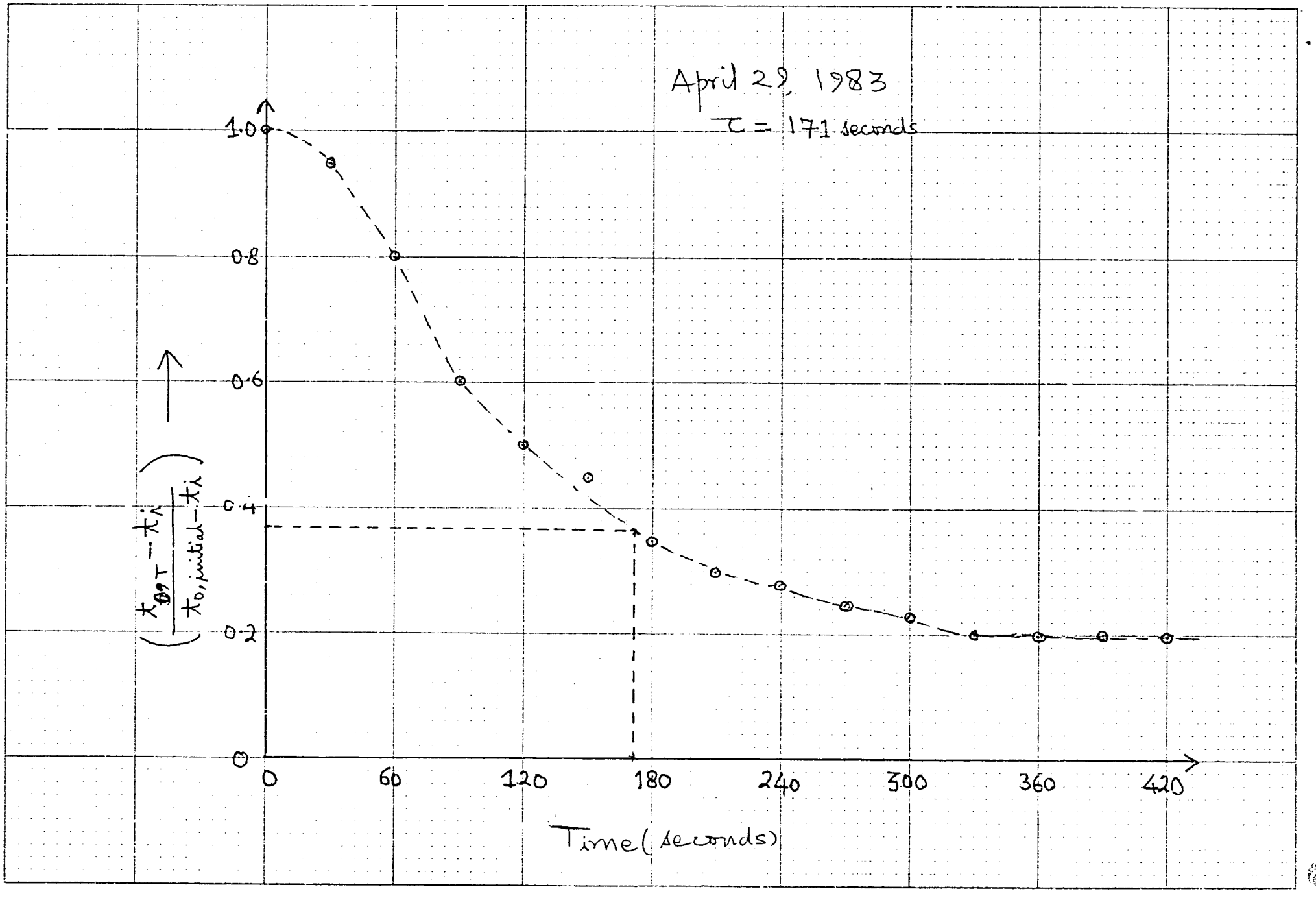

April 29, 1983
τ = 171 seconds
1.0
0.8
0.6
0.4
0.2
0
0
60
120
180
240
300
360
420
Time (seconds)
$\left(\frac{t_{0,T} - t_i}{t_{0,initial} - t_i}\right)$

Fig. 8

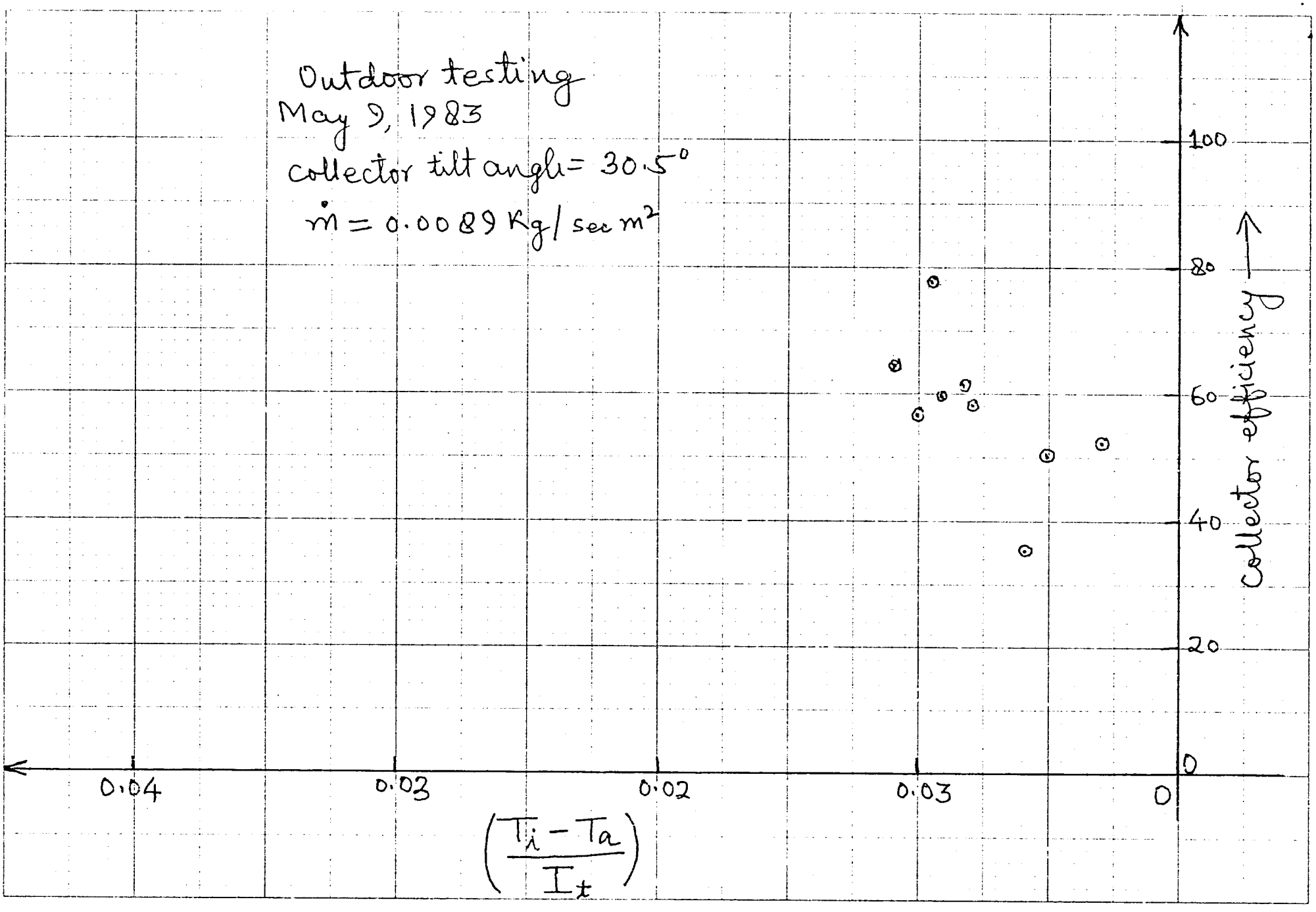
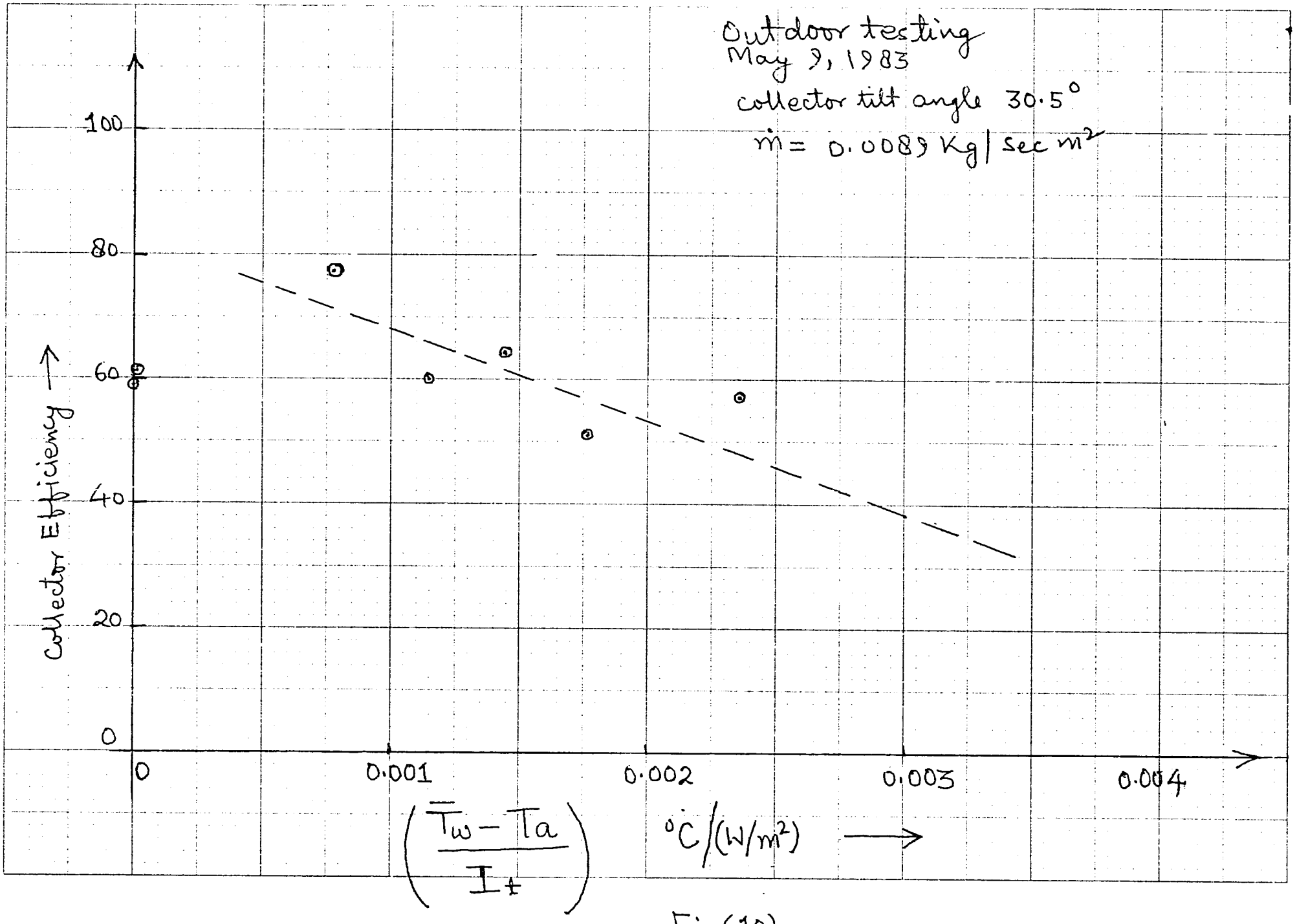



Fig.(9)

46 0780
K+E 10 X 10 TO THE INCH KEUFFEL & ESSER CO.




Fig(10)

46 0780
K+E 10 X 10 TO THE INCH
KEUFFEL & ESSER CO.

# TABLE 1

| S. No. | | CLEAR DAY April 21, 1983 $\dot{m} = 0.0216$ Kg/sec m$^2$ | SEMI-CLOUDY DAY May 9, 1983 $\dot{m} = .0089$ Kg/s.m$^2$ | CLOUDY DAY April 18, 1983 $\dot{m} = 0.0206$ Kg/sec m$^2$ |
|---|---|---|---|---|
| 1 | Hours of operation | 10.00AM – 3.00PM (EST) | 11.00AM – 4.00PM (EDT) | 10.00AM – 3.00PM. (EST) |
| 2 | Total solar energy incident on collector plane | 16.47MJ | 13.23MJ | 6.75MJ |
| 3 | Total energy collected by the collector | 9.90MJ | 8.10MJ | 5.58MJ |
| 4 | Overall efficiency | 60.1% | 61.2% | 82.6% |