SOLAR WORLD FORUM

Proceedings of the International Solar Energy Society Congress

Brighton, England, 23-28 August 1981

Edited by

DAVID O. HALL
King's College
London

JUNE MORTON
UK-ISES
London

Volume Four

PERGAMON PRESS

OXFORD · NEW YORK · TORONTO · SYDNEY · PARIS · FRANKFURT

U.K.	Pergamon Press Ltd., Headington Hill Hall, Oxford OX3 0BW, England
U.S.A.	Pergamon Press Inc., Maxwell House, Fairview Park, Elmsford, New York 10523, U.S.A.
CANADA	Pergamon Press Canada Ltd., Suite 104, 150 Consumers Road, Willowdale, Ontario M2J 1P9, Canada
AUSTRALIA	Pergamon Press (Aust.) Pty. Ltd., P.O. Box 544, Potts Point, N.S.W. 2011, Australia
FRANCE	Pergamon Press SARL, 24 rue des Ecoles, 75240 Paris, Cedex 05, France
FEDERAL REPUBLIC OF GERMANY	Pergamon Press GmbH, 6242 Kronberg-Taunus, Hammerweg 6, Federal Republic of Germany

First edition 1982

Library of Congress Cataloging in Publication Data

Main entry under title:
Solar world forum.
1. Solar energy—Congresses. I. Hall, D. O. (David Oakley) II. Morton, June. III. International Solar Energy Society.
TJ810.S725 1982 621.47 82-323
AACR2

British Library Cataloguing in Publication Data

International Solar Energy Society. Conference (1981:Brighton)
Solar world forum
1. Solar energy—Congresses
I. Title II. Hall, David O
III. Morton, June
621.47 TJ810

ISBN 0-08-026730-0

In order to make this volume available as economically and as rapidly as possible the authors' typescripts have been reproduced in their original forms. This method unfortunately has its typographical limitations but it is hoped that they in no way distract the reader.

Printed in Great Britain by A. Wheaton & Co. Ltd., Exeter

Headington Hill Hall,
gland

Maxwell House, Fairview Park,
0523, U.S.A.

la Ltd., Suite 104,
Willowdale, Ontario M2J 1P9, Canada

) Pty. Ltd., P.O. Box 544,
11, Australia

, 24 rue des Ecoles,
France

I, 6242 Kronberg-Taunus,
l Republic of Germany

ataloging in Publication Data

resses. I. Hall, D. O.
orton, June. III. Interna-
ciety.
621.47 82-323

guing in Publication Data
rgy Society. Conference

resses
)

olume available as economically and
the authors' typescripts have been
original forms. This method
ographical limitations but it is hoped
tract the reader.

n by A. Wheaton & Co. Ltd., Exeter

TABLE OF CONTENTS

Volume Four

SOLAR ELECTRICITY GENERATION 2683
SOLAR ENERGY IN DEVELOPING COUNTRIES 3105
SOLAR ENERGY INTERNATIONAL & NATIONAL PROGRAMMES 3151
AUTHOR INDEX 3351
SUBJECT INDEX 3359

Volume One

CONGRESS OPENING ADDRESS xiii
FARRINGTON DANIELS ADDRESS xvi
ACTIVE HEATING & COOLING IN BUILDINGS
I. System Performance—DHW Systems, Control, Collectors and Materials 1
II. System Performance—Space Heating Systems; Systems with Heat Pumps 253
III. Cooling and Air Conditioning; Cooking; Drying; Conversion to Work; Swimming Pools and Solar Ponds 515
IV. Thermal Energy Storage; System Test Methods 687

Volume Two

AGRICULTURAL PROCESSES 945
BIOMASS 1205
IMPLEMENTING SOLAR ENERGY 1363
INDUSTRIAL PROCESSES 1589

Volume Three

PASSIVE HEATING & COOLING IN BUILDINGS 1753
PHOTOCHEMISTRY, THERMOCHEMISTRY & ADVANCED SYSTEMS 2175
SOLAR RESOURCES 2309
SIMULATING & MODELLING 2503

SOLAR ELECTRICITY GENERATION

RAPPORTEUR'S REPORT
P.T. Landsberg 2687

KEYNOTE PAPERS

RESULTS OF THE UNITED STATES RESIDENTIAL PHOTOVOLTAICS PROGRAM
P.D. Maycock 2695

SOLAR THERMAL POWER GENERATION. THE EXAMPLE OF THE EUROPEAN 1 MW(el) POWER PLANT 'EURELIOS'
J. Gretz 2705

CONTRIBUTED PAPERS

CONCEPTUAL DESIGN OF A 500 kW/YEAR MASS-PRODUCTION PROCESS OF LOW-COST SILICON SOLAR CELL AND MODULE
K. Yamagami, S. Noguchi, K. Kurokawa & T. Horigome 2715

THE ROLE OF RESEARCH AND TECHNOLOGY DEVELOPMENT IN PHOTOVOLTAICS
R. Ferber, E. Costogue & R. Forney 2720

LARGE-SCALE PRODUCTION OF CdS/Cu_2S SOLAR CELL MODULES
B. Schurich, J. Worner & N. Abdelmonem 2726

CURRENT STATUS OF THE INVESTIGATION OF THE EVAPORATED CdS/Cu_2S SOLAR CELLS
J. Worner, B. Schurich & N. Abdelmonem 2732

LARGE AREA CADMIUM SULPHIDE THIN FILMS PRODUCED BY ELECTROPHOTETIC DEPOSITION
T.J. Cumberbatch, I.D. McInally, E.W. Williams, D.J. Gibbons, H. Clow, P.M. Dickinson, R. Hill, N.M. Pearsall, J. Woods, G. Russell & F. Poulin 2738

PHOTOVOLTAIC POWER FOR THE PEOPLE
P.R. Wolfe 2743

ON THE SIMULTANEOUS USE OF LAND FOR SOLAR ENERGY CONVERSION AND AGRICULTURE
A. Goetzberger & A. Zastrow 2750

A SERIES OF R & D ON SOLAR PHOTOVOLTAIC CONVERSION SYSTEMS OF JAPAN
K. Kurokawa, H. Akabane, H. Hosokawa & K. Murakami 2755

PROSPECTS FOR PHOTOVOLTAIC ELECTRICITY GENERATION IN WESTERN AUSTRALIA
R.R. Booth & S.G. Saunders 2760

PHOTOVOLTAIC ENERGY SYSTEM FOR RURAL TROPICAL HABITAT
C.E. Emetaram, E.D. Tani & R. Wijewardene 2767

PHOTOVOLTAIC POWERED VILLAGE LIGHTING SYSTEMS: A SYSTEM DESIGN EXPERIMENT
J. Avery, E. Berman & B. Pyle 2772

PHOTOVOLTAIC EXPERIENCE IN THE TROPICS
P.J. McKenzie & W.R. Bottenberg 2777

DESIGN OF LOW COST AND RELIABLE PHOTOVOLTAIC POWERED REFRIGERATOR FOR TROPICAL REGIONS CLIMATE
W.R. Anis, R.P. Mertens & R.J. Van Overstraeten 2784

DESIGN OF MINIMUM COST STAND-ALONE FLAT PLATE PHOTOVOLTAIC SYSTEMS
W.J. Kaszeta 2789

PHOTOVOLTAIC UTILITY-INTERACTIVE RESIDENCES FOR THE UNITED STATES
A.R. Millner, R.W. Matlin, S.J. Strong & R.J. Osten 2798

A JOINT INDIAN HEALTH SERVICE - DEPARTMENT OF ENERGY PHTOOVOLTAIC PROJECT TO PROVIDE ELECTRICITY AND DOMESTIC WATER FOR AMERICAN INDIANS
S. Reyes 2803

RESIDENTIAL PHOTOVOLTAIC APPLICATIONS IN THE UNITED STATES
S.J. Strong & R.J. Osten 2815

SOPHIA ANTIPOLIS PHOTOVOLTAIC SOLAR HOUSE IN OPERATION
D.J. Denis 2821

COMPUTERIZED FAULT ISOLATION OF LARGE SCALE MODULAR PHOTOVOLTAIC ARRAYS
C.S. Costanzo, K.E. Hogeland & V.V. Risser 2827

A PRACTICAL 40 WATT SILICON FLAT PLATE PHOTOVOLTAIC MODULE WITH IMMUNITY TO REVERSE BIAS HEATING DAMAGE AND MINIMAL POWER LOSS CAUSED BY SHADOWING OR LOW TEMPERATURE OPERATION
I.A. Lesk, N.G. Sakiotis & R.N. Kassner 2833

OVER 20% EFFECTIVE EFFICIENCY PHOTOVOLTAIC FLAT PANEL
A. Luque, A. Cuevas, J. Eguren & J. del Alamo 2839

ELECTRICITY GENERATION - PHOTOVOLTAIC STORAGE BATTERIES AND CONTROL
A. Dichler 2848

THERMOPHOTOVOLTAICS: AN ALTNERATIVE TO SIMPLE SOLAR CELLS
R.C. Neville 2857

NON-TRACKING PHOTOVOLTAIC CONCENTRATORS
E. Harting, D.R. Mills & J.E. Giutronich 2866

THE EFFECT OF INHOMOGENEOUS IRRADIATION ON EFFICIENCY AND ECONOMY OF SILICON SOLAR CELLS
A. Wagner 2871

CHARACTERIZATION OF A DICHROIS MIRROR USED IN A PHOTOVOLTAIC SYSTEM WITH TWO TYPES OF SOLAR CELLS (BICOLOUR SOPHOCLE)
D. Esteve, V.V. Pham, O. Soumaoro, F. Therez & G. Vialaret 2876

CONSTRUCTION AND FIELD TESTS ON A PARABOLIC TROUGH'S CONCENTRATOR'S PHOTOVOLTAIC MODULE
M. Guiffrida & M. Liquindoli 2881

CONSTANT FLUX REFLECTORS WITH SPHERICAL ABSORBERS
N. Tully 2882

PHOTOVOLTAIC INTERMEDIATE APPLICATION EXPERIMENTS
K.L. Biringer 2886

HIGH TEMPERATURE TESTING OF SOLAR CELLS UNDER CONCENTRATED SUNLIGHT CONDITIONS
E.K. Stefanakos, W.J. Collis & E.H. Martin 2891

2777

TAIC POWERED REFRIGERATOR FOR
rstraeten 2784

PLATE PHOTOVOLTAIC SYSTEMS 2789

CES FOR THE UNITED STATES
& R.J. Osten 2798

NT OF ENERGY PHTOOVOLTAIC
TIC WATER FOR AMERICAN INDIANS 2803

THE UNITED STATES 2815

E IN OPERATION 2821

ALE MODULAR PHOTOVOLTAIC
sser 2827

HOTOVOLTAIC MODULE WITH
AND MINIMAL POWER LOSS CAUSED
N
r 2833

IC FLAT PANEL
l Alamo 2839

ORAGE BATTERIES AND CONTROL 2848

SIMPLE SOLAR CELLS 2857

h 2866

N EFFICIENCY AND ECONOMY OF 2871

D IN A PHOTOVOLTAIC SYSTEM
SOPHOCLE)
herez & G. Vialaret 2876

IC TROUGH'S CONCENTRATOR'S 2881

BSORBERS 2882

ERIMENTS 2886

NDER CONCENTRATED SUNLIGHT
tin 2891

OPTICAL ANALYSIS OF NON-IDEAL PARABOLOIDAL CONCENTRATING REFLECTORS
S.V. Shelton 2892

A TOTAL SOLAR PHOTOVOLTAIC ENERGY SYSTEM
H.V. Smith 2903

THEORETICAL AND EXPERIMENTAL ANALYSIS OF TWO PASSIVE COOLING SYSTEMS FOR THE SOLAR CELLS WITH CONCENTRATION
A. Dumas & F. Draghetti 2908

STRUCTURAL DESIGN DEVELOPMENT OF A PHOTOVOLTAIC CONCENTRATING ARRAY USING FRESNEL LENSES
S. Broadbent & J.A. Sanders 2913

A MICROCOMPUTER BASED SUN TRACKING SYSTEM
A. Traca-de-Almeida, H. Jesus & L. Moura 2920

RECENT DEVELOPMENTS IN A SOLAR POWER GENERATOR
R. Almanza, F. Munoz, A. Valdes, E. Barrera & E. Montes 2926

A SPANISH 'POWER TOWER' SOLAR SYSTE. THE PROJECT CESA-1
A. Munoz Torralbo 2931

IMPLICATIONS, REQUIREMENTS AND RESTRICTIONS FOR SOLAR TOWER SYSTEMS WITH HIGH TEMPERATURE BRAYTON CYCLE
K.J. Erhardt 2936

100 kW SOLAR POWER PLANT IN CORSICA 'SOFRETES/BERTIN'
E. Bacconnet, M. Dancette & J. Malherbe 2941

LARGE PARABOLIC DISH COLLECTORS WITH SMALL STEAM- OR GAS-TURBINE OR STIRLING POWER CONVERSION SYSTEMS
K. Bammert & M. Simon 2950

ADVANTAGES OF LARGE PARABOLIC DISH SYSTEMS FOR POWER GENERATION
A.G. Sutsch 2951

EFFECTS OF A CIRCUMFERENTIALLY NON UNIFORM INCIDENT SOLAR FLUX ON THE WALL TEMPERATURE DISTRIBUTION IN A TUBE FLOW
M. Debiane & D. Blay 2960

ADVANCED SOLAR RECEIVERS - HIGH TEMPERATURE STEAM LOOP EXPERIMENTS
A.H. Campbell & H.L. Teague 2967

COMPARISON OF ANALYSIS AND TEST RESULTS FOR A CENTRAL RECEIVER
P.S. Bremner & R.K. McMordie 2972

APPLICATION OF SOLAR CELLS IN SOLAR TOWER PLANTS
F.K. Boese, H. Kiupel, U. Leuchs & H.G. Spillekothen 2977

STUDY OF LOW POWER ENGINES: THERMODYNAMIC CONVERSION OF SOLAR ENERGY
C. d'Amelio, M. Blasi & R. Tuccillo 2983

SOLAR SYSTEMS WITH LIQUID METAL MAGNETOHYDRODYNAMIC ELECTRIC POWER GENERATORS
H. Branover, A. El-Boher & A. Yakhot 2993

TWO YEARS' OPERATION OF THE 30/50 kW_e SOLAR FARM AT GETAFE/SPAIN
R. Koehne, M. Kraft & A. Perez Vidal 2999

SOLAR ACTIVATED POWER GENERATION UTILISING A MULTI-VANE EXPANDER AS A PRIME MOVER IN AN ORGANIC RANKINE CYCLE
M. Hussein, P.W. O'Callaghan & S.D. Probert 3006

THEORETICAL AND EXPERIMENTAL ANALYSIS OF TWO PASSIVE COOLING SYSTEMS FOR THE SOLAR CELLS WITH CONCENTRATION

A. DUMAS[+], F. DRAGHETTI[+]

[+]Istituto di Fisica Tecnica, Fac. di Ingegneria, Università di Bologna, Italia

ABSTRACT

The thermal behaviour of a finned massive core used like passive cooling device has been, theoretically and experimentally, compared with the one of a finned heat pipe. The results show that the almost total reduction of the thermal resistance of the core causes a drop of the solar cell temperature and, consequently, an increase of its efficiency up to 30%, depending from geometrical and thermophysical parameters.

KEYWORDS

Heat pipe;passive cooling system; solar cell cooling.

INTRODUCTION

It is well known that the photovoltaic cells, impingued by radiative flux, produce electrical and thermal energy. The coupling of passive cooling systems to the cells can be sufficient, if the concentrated radiative flux is less than 100 kw/m^2, to dissipate the developed heat and to maintain the working temperature of the cell at values lower than 360 K. A simple passive cooling device is a metallic full core, finned on the side-wall, with a constant cross section of suitable shape, whereas the top is the face of the solar cell. The cooling efficiency of this system is reduced by the thermal resistance of the core, the higher the less is the cross section surface. The study of this effect, reported in this paper, has been performed, in former stage, theoretically, by two mathematical models of the device above described, different between themselves only by the bounded or infinite conductance of the core and indicated, henceforth, respectively HN and HT. In a latter stage, two mild steel works like passive cooling device have been built, having the former a massive core and the latter a heat pipe, working the face of the cell as evaporator and the rest of the surface as condensator.

MATHEMATICAL MODELS

With reference to the Fig. 1 we assume the following hypotheses:
-- the cross section of the core is equal to the cell surface;
-- no thermal gradient across the lens and between cell and its face;

-- no conductive heat flux between truncated cone and cell;
-- temperatures of the external ambient air T_A, of the truncated cone surface T_S, of the enclosure air T_E and of the cell T_C are uniform, furthermore $T_S = T_E$;
-- same convective coefficients for core and fins;
-- the only axial gradient can be different from zero in the core, (when it is zero, the HT model is described).

The heat balance between two cross sections distant dz gives, in steady-state conditions,:

$$d^2T/dz^2 = (T - T_A)2U/(\lambda R) \quad (1)$$

where $U = (h_r + h)(2\pi R - ns + 2n\varepsilon L)/(2\pi R)$
with s,L,ε and n respectively thickness,length, efficiency and number of the fins, and with R and λ the radius of the core cross section and the thermal conductivity coefficient of core and fins.
The boundary conditions are:

$$dT/dz = Q_D(T) \qquad z = 0 \quad (2)$$
$$dT/dz = 0 \qquad z = H \quad (3)$$

where H is the height of the fins.
The thermal power $Q_D(T)$ dissipated by the cooling device is dependent from the cell temperature and is unknown, but at z = 0 we have the global heat balance given by $Q_D(T) = Q_I - Q_W(T) - Q_E$ (4)
where the terms at right-hand are respectively the radiative power impinguing the cell, the electrical power obtained and the thermal power transferred to the enclosure. This last is equal, in steady conditions, to the thermal power dissipated by the enclosure, so that we have

$$U_C(T_C - T_S)S_C = U_S(T_S - T_A)S_S \quad (5)$$

where S is a exchange surface, U is an overall heat-transfer coefficient, and we can calculate Q_E if the cell temperature is known.

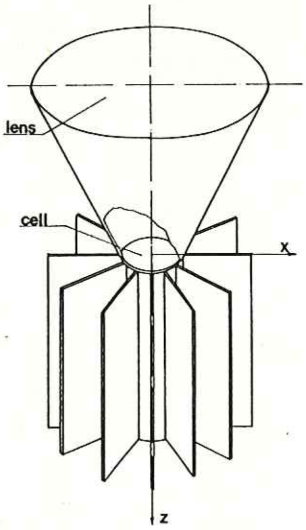

Fig. 1. Design of the device

The relationship, used for the coefficients of free convection between external ambient air and fins is taken from Van Den Pool and Tierney (1977), whereas for the forced convection the relationship given from Giulianini, Cocchi and Vaccari (1966) is used. The radiative exchange coefficient h_r is given by $h_r = e\sigma_o(1 - \sin(\phi/2))(T + T_A)(T^2 + T_A^2)$
with σ_o is the Stefan-Boltzmann constant, e is the wall emissivity and ϕ is the dihedron between the fins.
The equation (1) with the boundary conditions (3,4) has been solved by a standard finite difference method. A first guess of the temperature's values permit to calculate h, h_r and Q_D so that these can be utilized to determine new values of temperature until the max difference between the old and the new solutions is less than .001.
In the case of HT model, the thermal balance is very simple and gives:

$$Q_I = Q_D + Q_E \ ; \qquad Q_D = H(T_C - T_A)(2n\varepsilon L + 2\pi R - ns)(h_r + h)$$

and the cell temperature is obtained by standard algorithm.

Numerical Results

It is immediate that the thermal behaviour of two models is dependent by numerous parameters, but, here, for the sake of brevity the Figures from 2 to 4 show the thermal behaviour of the system and the cell efficiency compared with only some parameters.
Unfortunately, the HT model describes only an ideal heat pipe since the heat flux, from the evaporator to the condensator, passes through several thermal resistances connected in series. A semi-empirical evaluation of their sum, that is to say the global thermal resistance, gives $R_g = 0.18$ K/w. The Figure 5 show this effect, with

effects on the cell temperature;
-- a length of the fins less than 0.1 m is recommended for both models;
-- the ratio height/diameter for the core must be less than 5 in HN model;
-- the almost total reduction of thr thermal resistance of the core causes a drop in temperature of the cell and, consequently, an incr-ase of its efficiency up to 30% when the radiative flux is 100 kw/m^2;
-- the presence of a light wind (v = 1 m/s), as in the moutains, permit a solar cell system with a concentration ratio higher than 100, using heat pipe as core;
-- the weight of the device is an important parameter to design a solar photovoltaic plant

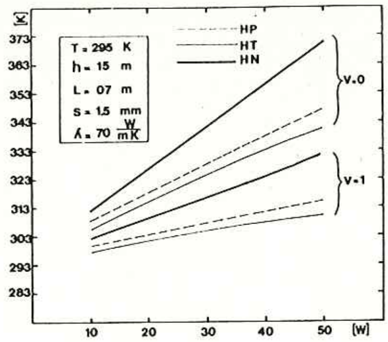

Fig. 5. T_C vs. Q_I

EXPERIMENTAL CHECKING

Utilizing the previous results, two cooling devices have been built, as shown in Fig. 6, the former having a full massive core, the latter a heat pipe as a core, whereas the fins were welded in both cases. The cylindrical tube of the heat pipe is a mild steel work, whereas the wick structure is constituted by four layers of stainless steel net of about 80 meshes/cm and held toghether by spot weldings. Bidistilled water, as working fluid, was, in a working time of five minutes, the cause of a rapid generation of corrosion with working end. In place of the water, acetone was used. The photovoltaic cells was nicely supplied from the Laboratory L.A.M.E.L.- C.N.R. of Bologna. The radiative flux was obtained by a tungsten lamp of 500 W and collimated by an optical system at low efficiency, so that it was possible to obtain a value of 30 as a maximum concentration ratio.
The Figure 7 show[2] the results of several tests of the two passive cooling devices toghether with the corresponding theoretical results, indicated as HN_t and HP_t, these last only for vertical position of the devices. It is immediate that the central belly of the slopes depending by bad working of the fins in horizontal position of the devices. It is worthy to note the pleasant agreement among the experimental data and the theoretical results, remembering that no welding thermal resistance has been accounted in the mathematical models.

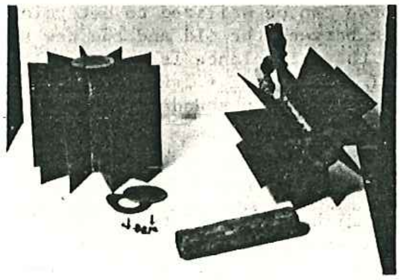

Fig. 6. Experimental devices

[2] The value of Q_I is wrong: Q_I = 12 W

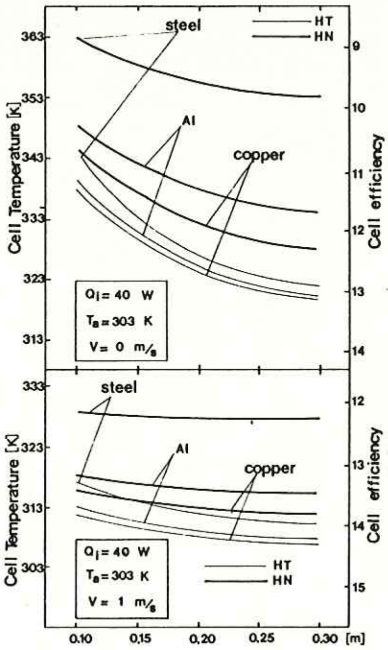

Fig. 2. T_C and ε vs. the fins length

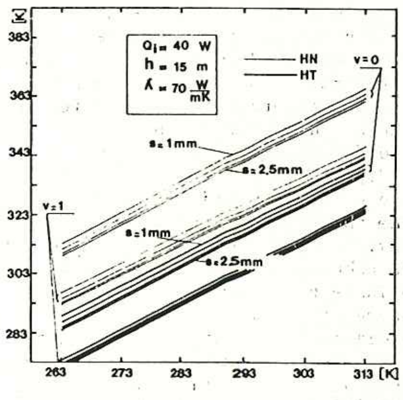

Fig. 3. T_C vs. T_A at different values of thickness of the fins

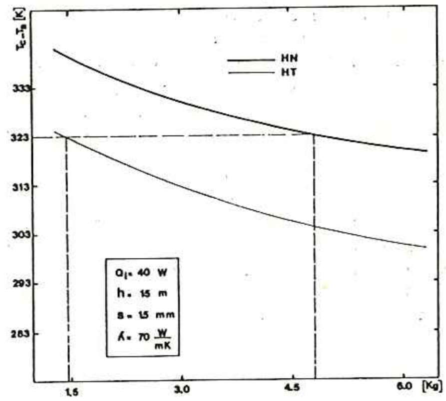

Fig. 4. Influence of the fins number in terms of weight on the difference$(T_C - T_A)$[1]

the slopes indicated as HP.

By these results it is possible to adfirm that

--the thermal power dissipated by the enclosure can be disregarded;

--the thickening of the fins causes a high rise in weight of the device with scarce

[1] The temperature scale is wrong: $(T_C - T_A)_{true} = (T_C - T_A)_{wrong} - 273$

Since the acetone cannot, in a wick structure, rise up, for capillarity,more than 6 cm, increasing the inclination of the device, the heat pipe does not work more. In fact, the greater is the contents of acetone the greater is the inclination angle of working stop. On the contrary, when the heat pipe is assisted by the gravity, in our case the evaporator turned upside-down, better results are obtained reducing the contents of the working fluid.

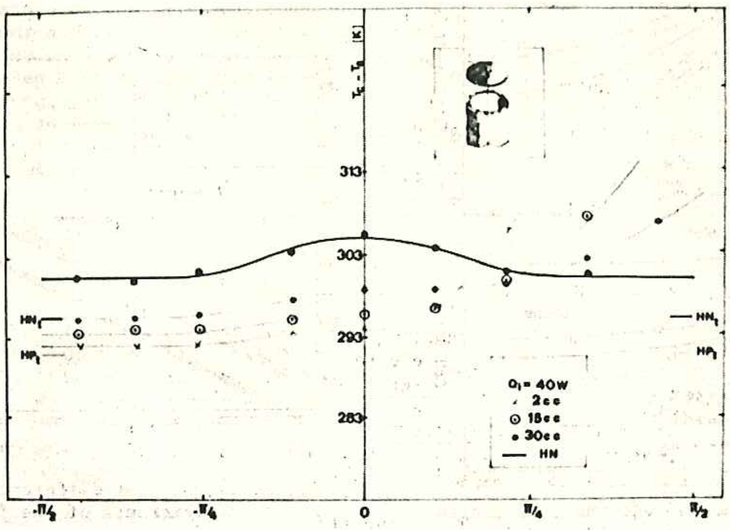

Fig. 7. The difference (T_C- T_A) vs. iclination angle

CONCLUSIONS

All results point out that the use of a heat pipe is a powerful tool in a passive cooling system and in particular it is to note:
-- all structure is very light;
-- itis possible to utilize concentration ratios greater than 100;
-- other designes,suggested by the previous tests could give better performances.

REFERENCES

Giulianini, A., Cocchi, A., and A. Vaccari (1966). Il Calore, 11, 1-11.
Van Den Pol, D. W., and J. K. Tierney (1973). J. H.T. ASME C, 95, 542-543