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히이트파이프를 이용한 태양열 온수급탕 시스템에 관한 기초 실험 연구

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An Experimental Study on the Utilization of Heat Pipes for Solar Water Heaters

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요 약

본 논문은 히이트 파이프를 이용한 태양열 온수 급탕 시스템의 제작 및 그 열성능에 관한 내용이다. 국내 기후에 적합한 모델을 도출하기 위하여 본 연구에서는 여러번에 기초실증 실험을 수행하였다. 히이트 파이프는 구리로 제작하였으며 증발부, 단열부 및 응축부의 길이는 각각 1700mm, 100mm, 그리고 200mm이다. 증발부는, 특히 효율적인 집열을 위하여 얇은 구리로 만든 핀(fin)을 부착하였다. 연구결과를 살펴보면 작동 유체의 종류, 윅(wick)의 유무, 표면 처리 정도 그리고 그 밖의 여러 설계인자에 따라 히이트 파이프를 이용한 태양열 온수 급탕 시스템의 열성능이 적지 않은 영향을 받을 수 있음을 나타내고 있다.

Abstract

This paper reports the performance of solar domestic hot water systems manufactured with heat pipes. A series of tests were conducted on a number of systems to elicit the most suitable configuration of the system for possible commercialization in Korea. The heat pipe is made with a copper tube and the respective length of the evaporator, adiabatic, and condenser sections are 1700mm, 100mm and 200mm. The evaportor section is finned with a copper plate to increase solar input for its proper operation as a heat pipe. Results show quite an interesting performance data stemming from the difference in working fluids, presence of wick, and other various design parameters associated with the collection and utilization of solar energy.

I. INTRODUCTION

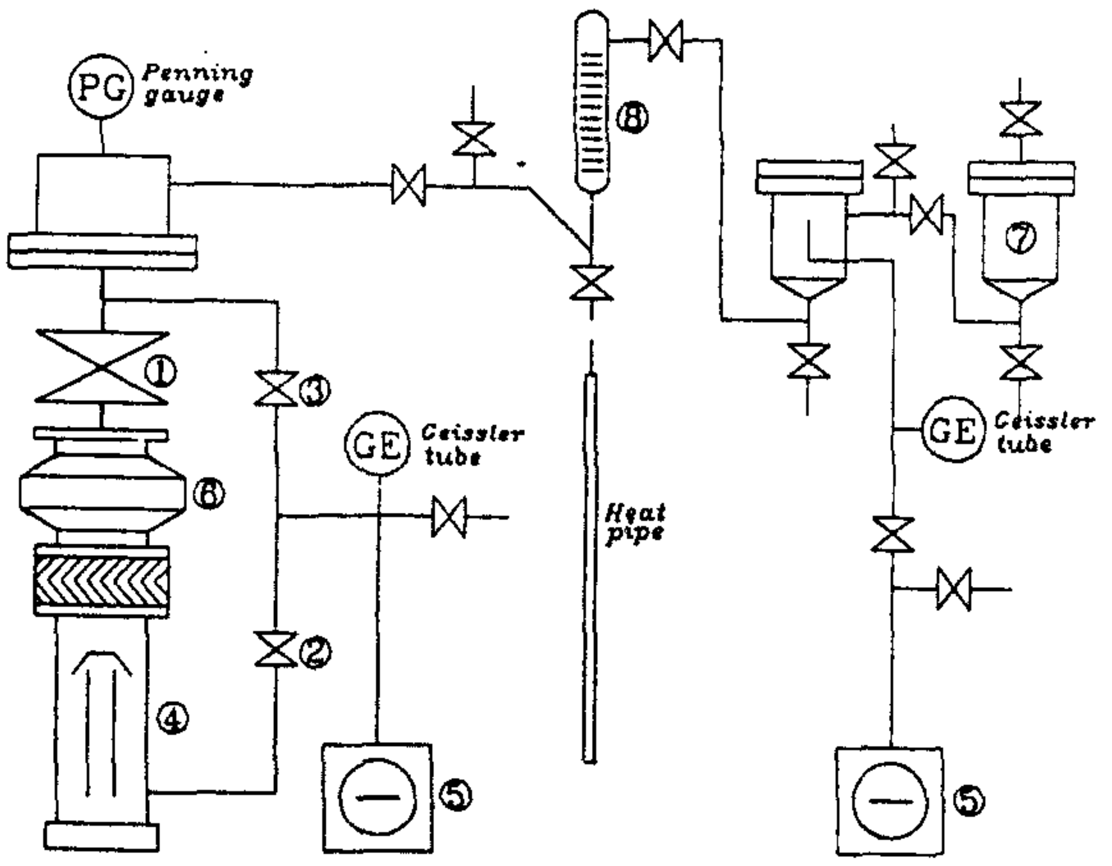
The use of heat pipes offers several advantages renders flexibility in operation and application, as they are very efficient in transporting heat even under a small temperature difference (1). Heat pipes are currently utilized in many energy systems according to their needs in industrial areas and aerospace applications including the solar system considered in the present analysis.

The first area that appears most appropriate for heat pipe application is domestic hot water heating. Hot water in the resident sector accounts for some portion of the nation's energy consumption. The amount of energy required to heat domestic water is significant, even in comparison with the space heating requirement. Moreover, the environmental issues linked to the use of fossil fuels give great incentives to harness alternative energies where possible.

The goal of the present work was to develop a solar domestic hot water system with heat pipes. A number of systems with different configurations and working fluids have been designed and their performances are tested to elicit the most feasible model considering the various limiting conditions now present. A full scale system and five trial systems on a reduced scale were analyzed in this regard. The performance data obtained from the indoor experimentation on heat pipes wre also extended in designing these solar systemsm(2, 3). Some other major design parameters examined in the present study include : types of heat pipe, coating materials for the evaporator section and the shape of storage unit for maximum thermal stratification.

II. MANUFACTURE OF HEAT PIPES

The pipes were initially evacuated using vacuum pumps(rotary and diffusion pumps) after a series of cleaning processes to remove possible contaminants, which can affect the performance and life of heat pipes : The pipe is first pumped down at the ambient temperature; and then, the pumping is continued while the pipe is heated(4, 5). Since high vacuums are required, this was a time-consuming process. Pipes were evacuated to 10E-5 torr. Following evacuation, the working fluid was sucked into the pipe through a special valving arrangement and the filling tube attached at the upper end was flattened to the thickness of a sheet of a paper. This process required up to an hour for each pipe. Fig. 1 shows the rig used for heat pipe evacuation and charging in the present study.



1:Main valve 2:Fore-line valve
3:Roughing valve 4:Diffusion valve
5:Rotary pump 6:Cyro trap
7:Mass cylinder 8:Stainless container

Fig. 1 A layout of the rig used for the heat pipe evacuation and filling

Ⅲ. SYSTEM DESCRIPTION

The solar collectors are prepared with heat pipes of copper whose major dimensions are 9.52mm o.d., 8.12mm i.d., and 2000mm length. Since gravity assisted heat pipes should permit maximum liquid flow rate by having a comparatively large pore size, the wrapped screen week of 100 mesh is used. The respective length of the evaporator, adiabatic, and condenser sections are 1700mm, 100mm, and 200mm. Here the adiabatic section is created by externally insulating the appropriate portion of the heat pipe fitted into the storage tank. To increase heat input(i.e., absorbed solar radiant energy), the evaporator section of tube is finned with a thin copper plate of 0.3mm and contained in a case with single glazing. The outer surface of the evaporator section exposed to the sun has been treated to have selective optical characteristics either by the black-chrome coating or by spraying black paint with seclective optical characteristics. The two-phased closed thermosyphon is also tested as a heat collection device, which is nothing more than a wickless heat pipe with a liquid reservoir at the bottom.

There are number of candidates for the working fluid that are compatible with copper. For the required operating temperature range of 20～100℃ for solar application, aceton, methanol, ethanol, distilled water, and ethanol-distilled water mixture were selected and tested as the possible candidates for the working fluid. However, in addition to being compatible, the fluid must be chemically stable over the operating range of the system and also be nonfreezing at very low ambient temperatures. The water storage tank of the system is made of copper and has 150 liter capacity insulated with 50mm polyurethane foam. The condenser portion of heat pipes, where the fluid surrenders heat to the colder surroundings(i.e., water in this case), is directly inserted into the storage tank. This configuration has shown the best performance data compared to the other cases considered in the present study.

Table 1. Design summary of the solar collector.

ITEM		SPECIFICATION
TYPE		Panel-type Flat Plate
OVERALL DIMENSION		680 × 1700 × 55(× 3EA)
ABSORBER PLATE DESIGN		Heat Pipe and Sheet Type
ABSQRBER SURFACE TREATMENT		Bl-Cr electric Selective Black Spray Coating
ABSORBER PLATE	MATERIAL	Copper
	THK.	0.3 mm
	AREA	2.24 m^2(1.12 × 2)
HEAT PIPE	MATERIAL	Copper
	SPC.	9.52 mm O. D.
	THK.	t 0.7 mm
CASE	MATERIAL	Sus 304
	THK.	1.5 mm
GLAZING	MATERIAL	Single Tempered Glass
	THK.	4 mm
	TRANSMITTANCE	93%
INSULATION	MATERIAL	Glasswool + Compressed film
	THK.	20 mm + 1 mm

The design of the full scale system, which consists of 12 heat pipes, is based on the performance results of trial systems made of the same material. Each of the five trial systems is built with a single heat pipe to simplify its experimental investigation. The design specifications of trial systems are given later(in Table 3). Tables 1 and 2 summarize the design parameters of the full scale unit(i.e., datails of solar collector and storage tank) built and tested in the persent analysis.

Table 2. Storage tank design specifications.

ITEM		SPECIFICATION
TOTAL CAPACITY		150 Liter
HEAT EXCHANGE TYPE		Direct Type
INSULATION		Polyurethan Form, 50 mm
OUTER CASE	MATERIAL	F. R. P.
	SPC.& THK.	ϕ450 × L 2100, t 1.5 mm
CONTAINER (TANK)	MATERIAL	Stainless Steel
	SPC.& THK.	1500 L(body) ϕ350 (end), 1.5 mm
WATER DISTRIBUTOR		PVC ϕ21.9 O.D.

Ⅳ. MEASUREMENTS

The performance of the five trial systems built on a reduced scale and a full scale system have been tested outdoors side by side with the aid of a data acquisition system capable of handling 60 channels. The solar collector unit of each system is sloped at 45° toward the south. Each series of tests was commenced at 9AM just after the tanks had been filled with fresh supply water from mains. In order to obtain typical daily data with clear skies, test measurements were mostly conducted on sunny days.

Nine thermocouples are mounted directly onto the outer walls of the heat pipe for each system to measure its temperature distribution during the heat pipe operation by the solar heat input. The mean temperature of water in the storage tank was calculated by taking the weight-volume average of 9 measured temperature points. Each data channel is scanned for every 20 seconds and the averaged values of the measured data are stored in memory on a fifteen minute time step to check the existence of the steady state.

V. RESULTS AND DISCUSSIONS

Table 3 gives the details of five mini systems(the trial systems built on a reduced scale) to analyze the performance of heat pipes and thermosyphons for the different types of working fluid and surface coating. Of the five mini systems tested, two of them are built with thermosyphons. The experimental results of these mini systems were extended to draw out the most practical system parameters in designing a full scale unit.

Table 3. Details of the mini systems built in the present study.

TYPE	A	B	C	D	E
Working Fluid	Water	Metanol	Acetone	Ethanol	Ethanol
Absorber Surf. treatment	Selective Spray	Selective Spray	Selective Spray	Bl-Cr	Bl-Cr
Collector Area (m^2)	0.17	0.16	0.15	0.16	0.15
Storage Tank Capacity	11	15	11	11	15
Heat Pipe type	Thermo-syphon	SUS Wick	SUS Wick	SUS Wick	Thermo-syphon

In studying the system performance, the following dimensionless variables are defined to systematically analyze the outputs from a series of tests :

$\Phi = (T-T_{ave})/(q_{ave}/U_L)$,

$\xi = x/L$,

$\tau = t/t^*$,

$\phi = (T-T_i)/(q_{ave}/U_L)$

What follows repersents the operational characteristics of each system using these dimensionless variables. The figures involved illustrates how the detailed results are correlated with the dimensionless variables in analyzing the heat pipe performance and understanding the major system parameters.

Each of the Figs. 2, 3, 4, and 5 shows the outputs of nine representative thermocouples, five in the evaporator section, two in the adiabatic section, and two in the condenser section for the mini system built in the present analysis. As shown, each figure describes the measured exterior wall temperature distribution at different times. During periods of low solar radiation, the temperature profiles are somewhat different from those of the hours with high solar input. These results might be interpreted to suggest the possibility that better system performance could be achieved by using a heat pipe instead of a thermosyphons.

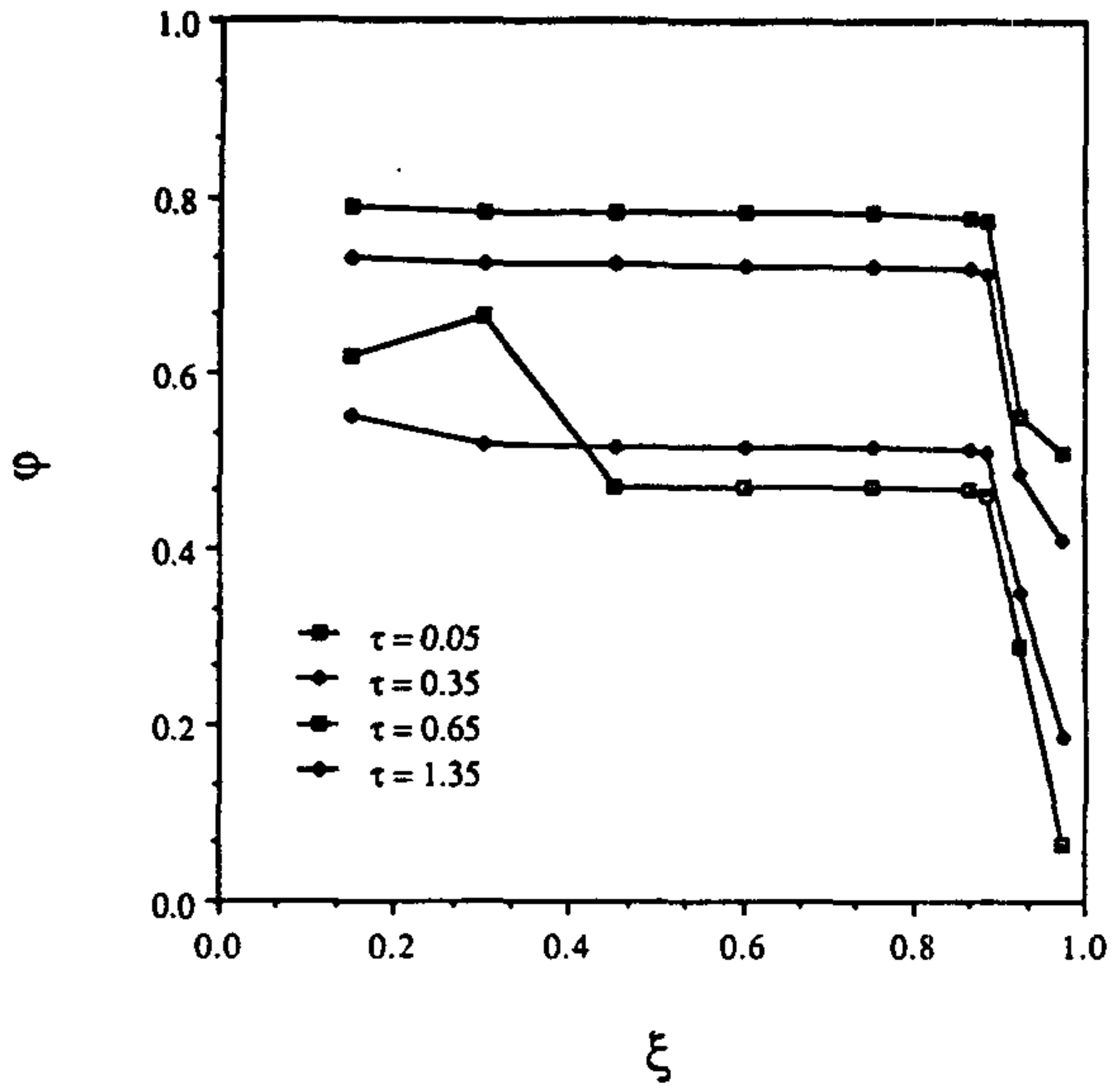


Fig. 2 Temperature variation at the outer wall of the heat pipe(B-type).

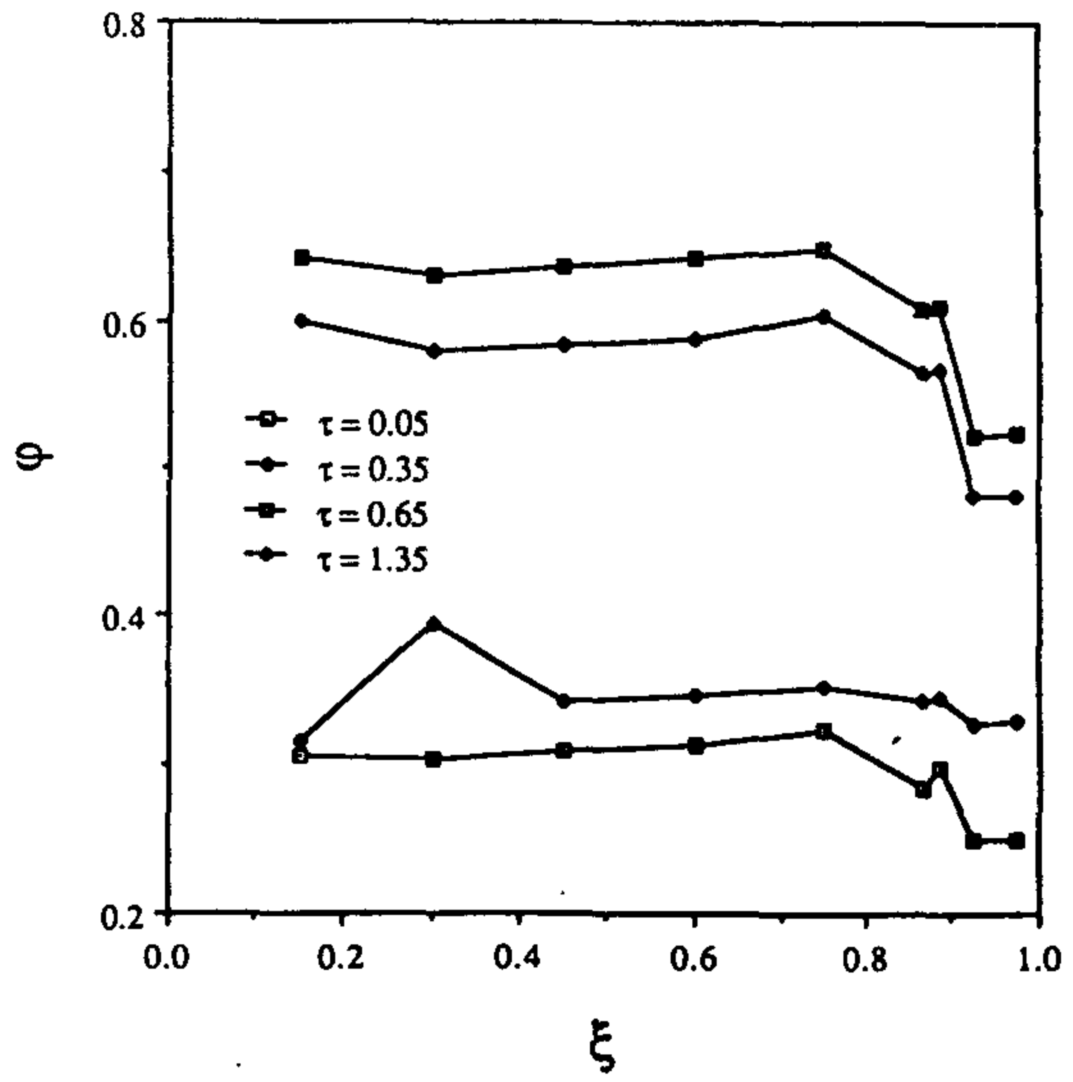


Fig. 4 Temperature variation at the outer wall of the heat pipe(D-type).

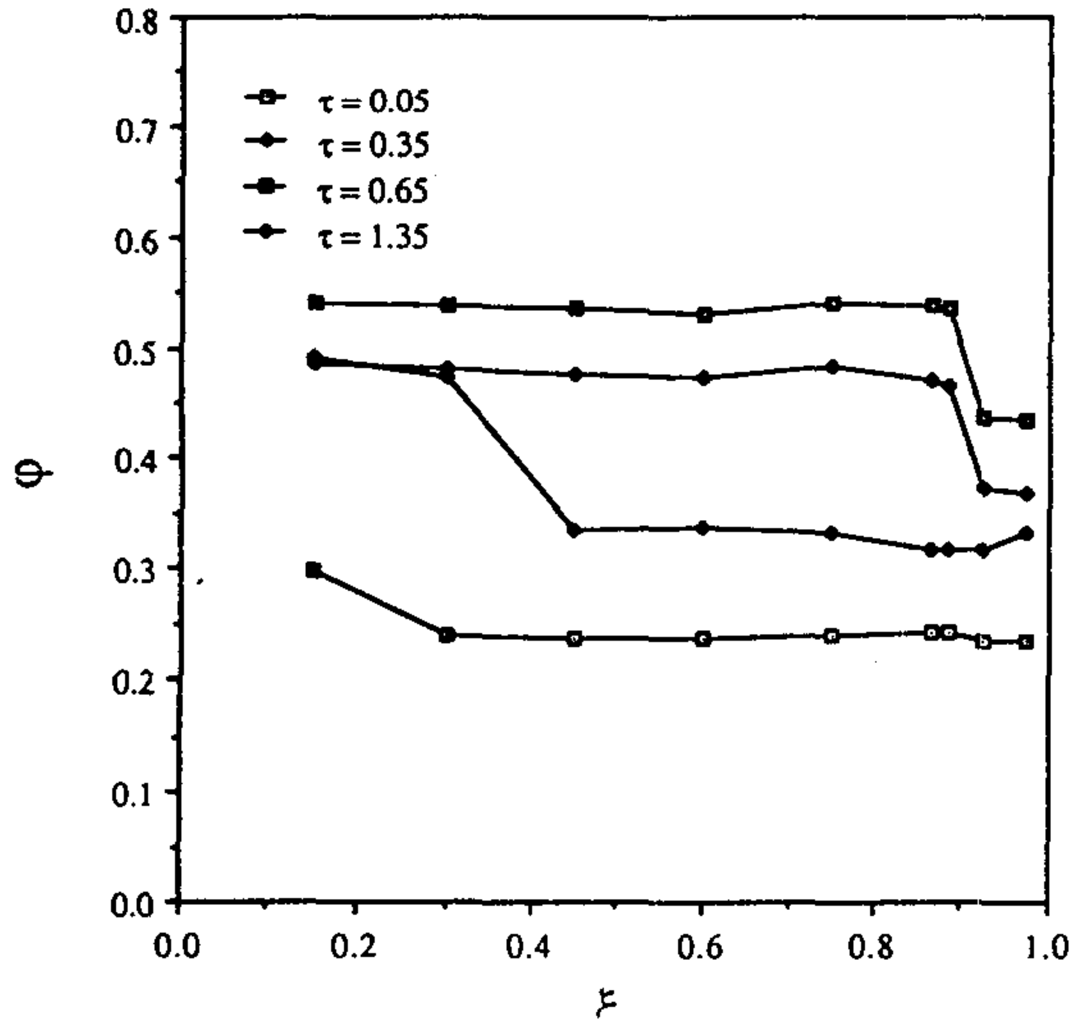


Fig. 3 Temperature variation at the outer wall of the heat pipe(C-type).

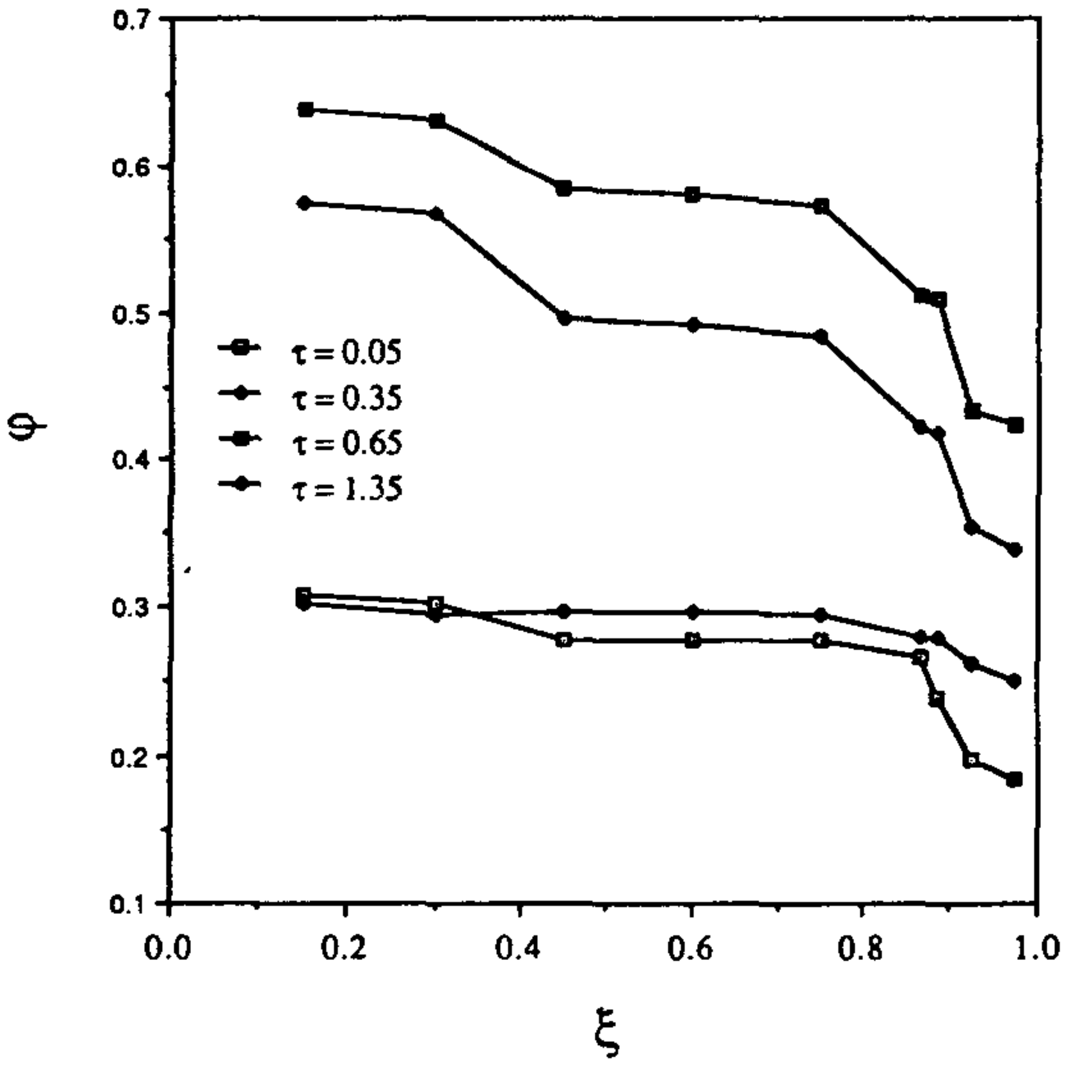


Fig. 5 Temperature variation at the outer wall of the heat pipe(E-type). B

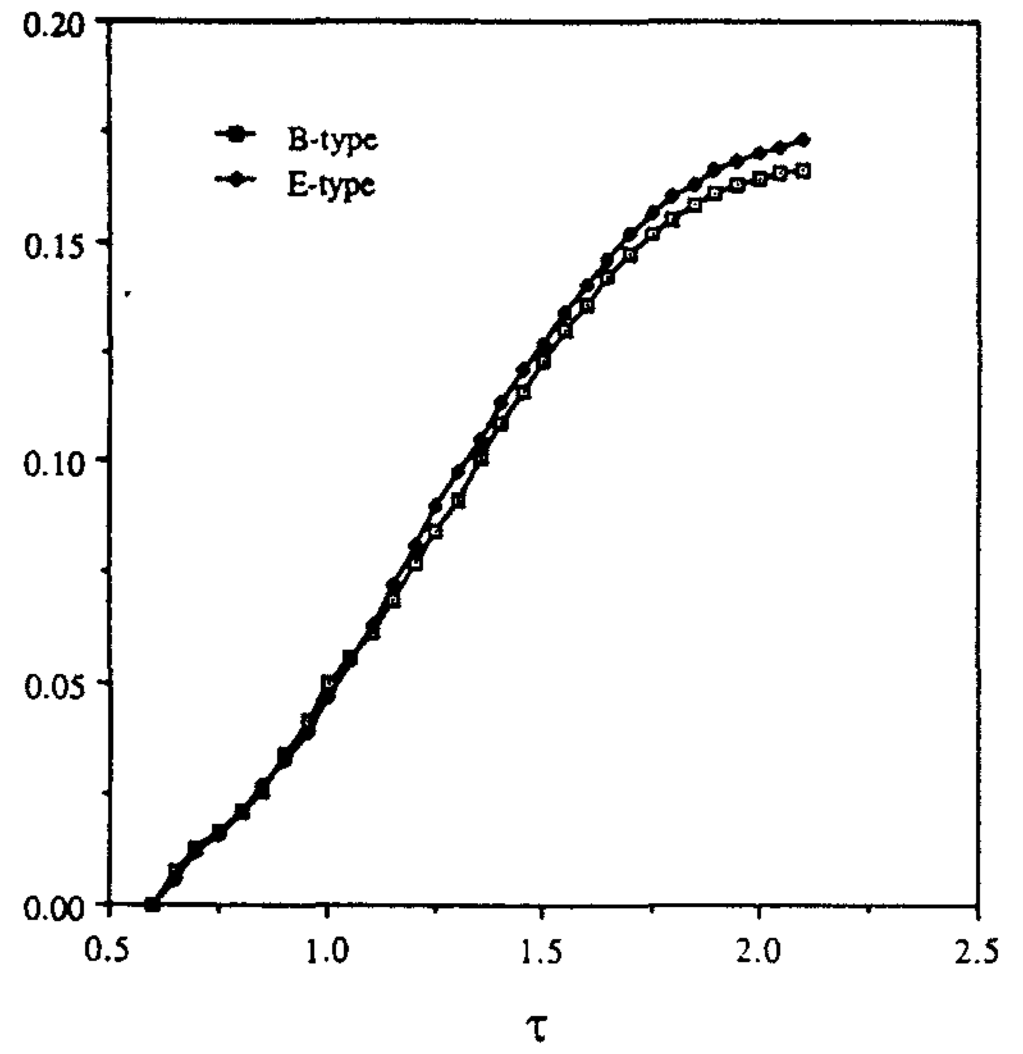


Fig. 6 Comparison of the tank water temperatures between two different systems(B, E-type).

Fig. 6 compares the average water temperature within the storage tank for two mini systems, B and E. No appreciable difference is observed throughout the hours of operation. This result is quite contrast to what could be anticipated from the Figs. 2, 3, 4, and 5.

Fig. 7 gives the typical performance data of our full scale system on a clear day. Although the average water temperature increases monotonically with time, temperatures measured by the thermocouples attached to the fin and the outer wall of a heat pipe show some fluctuations, especially during the hours of low solar radiation.

The tank temperature distribution is an extremely complicated function of the energy delivery, the energy loss, and the mixing effect caused by the layers of water body at different temperatures. Heat transfer within the storage tank is mainly governed by convection phenomena which results in the redistribution of temperature: The uniformity of temperature is attributable to the superior heat transfer associated with the colder fluid near the bottom and the availability of hot water at the top

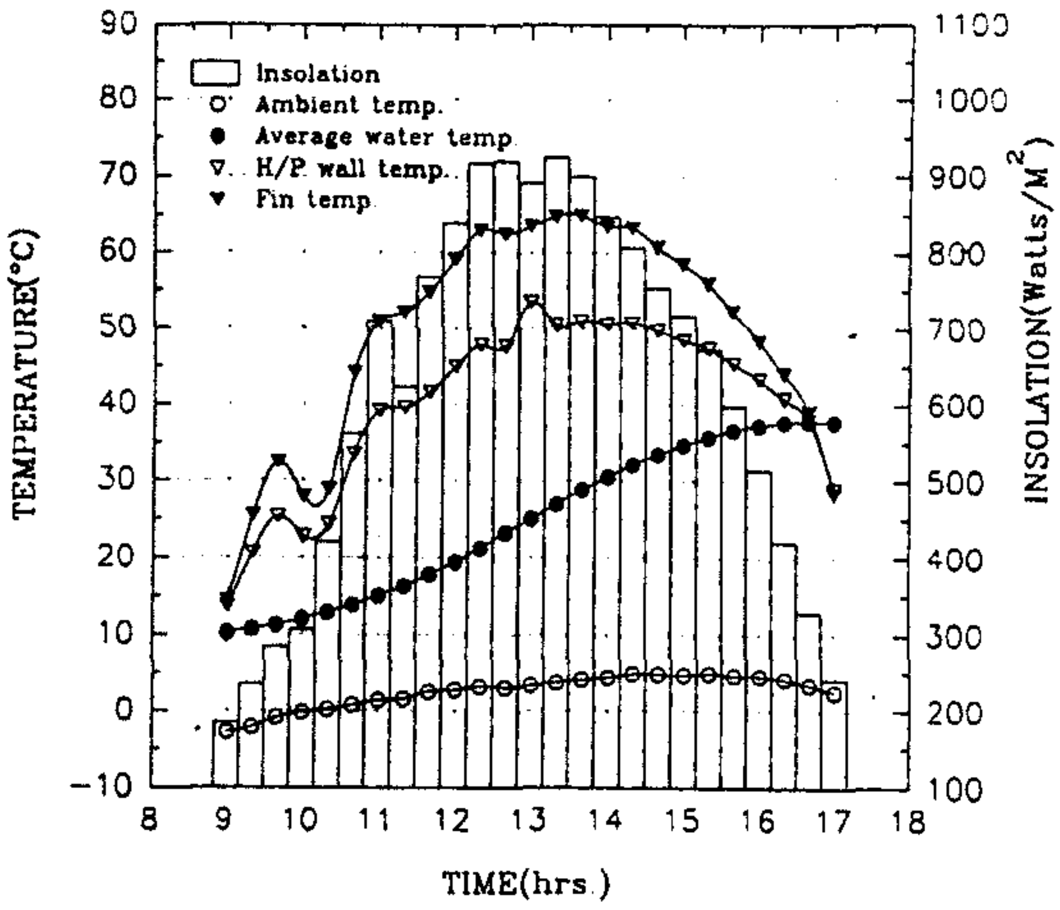


Fig. 7 Thermal performance of the full scale system on a clear day.

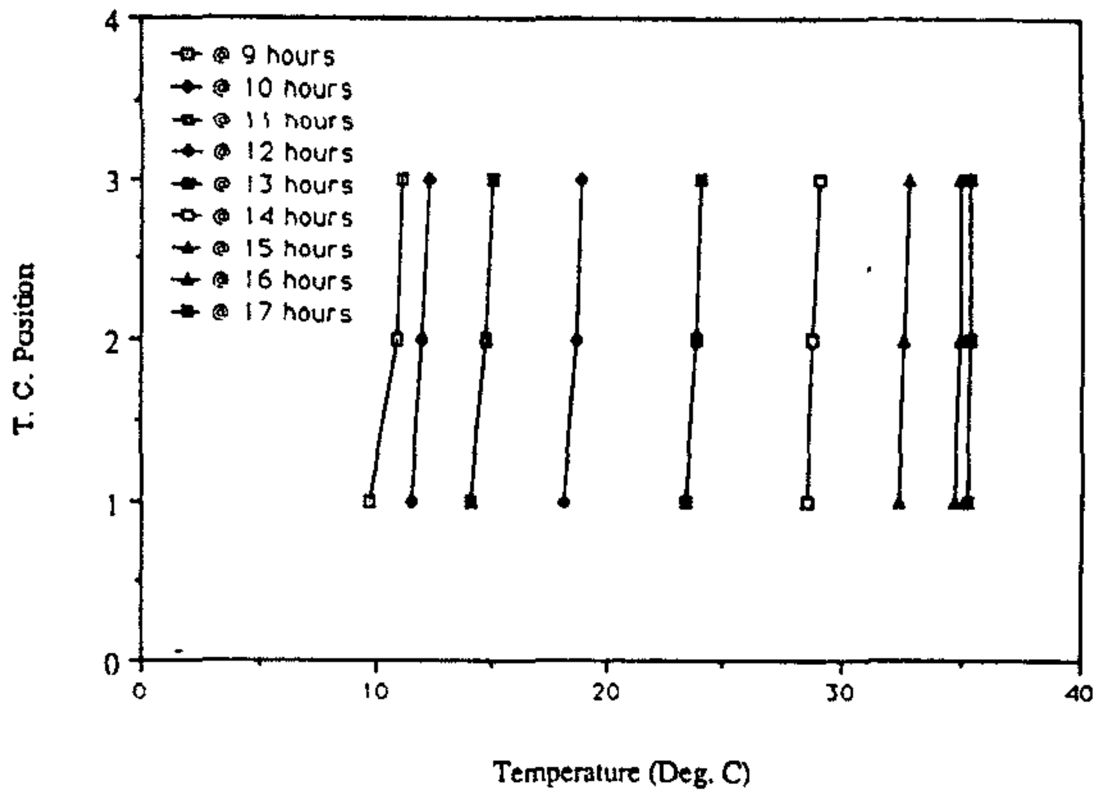


Fig. 8 Temperature measurements of water within the storage tank at different times.

of the tank. Fig. 8 shows the temperature variation of three locations within the storage tank at various times on a typical clear day in February. The mixing effect of the natural convection within the storage tank is well demonstrated.

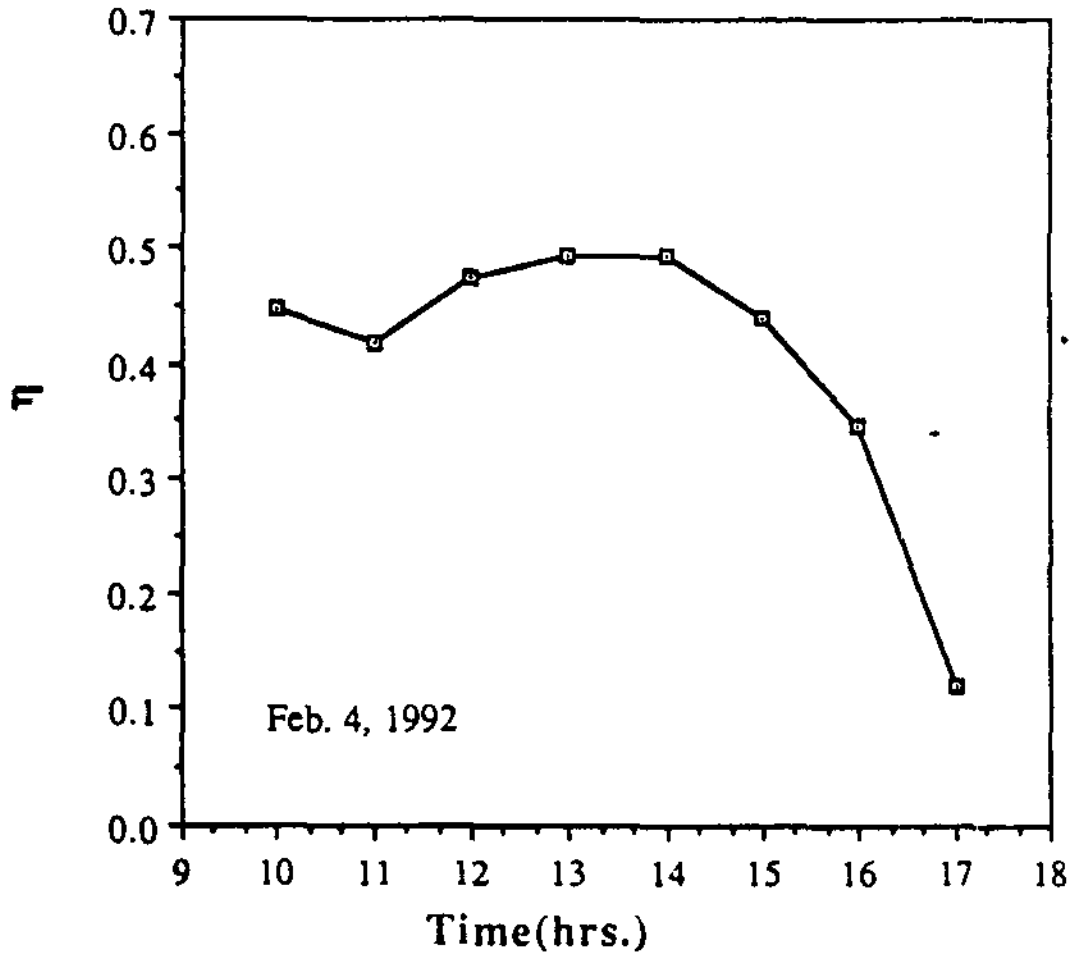


Fig. 9 Hourly values of the system efficiency.

Fig. 9 shows the hourly variation of the cumulative system efficiency. The cumulative system efficiency is defined as the total energy transferred to the storage tank divided by the total energy incident on the system(evaporator section). As shown, the hourly value measured for the period between 16 and 17 hours drops sharply due to low solar input. The average daily system efficiency is calulated to be 45%, which appears to be quite high compared to the other solar domestic hot water systems built and tested by our research team since 1986.

Ⅵ. CONCLUSIONS

A number of conclusions can be drawn from the present study. However, the major design parameters and the limited scope of this study should not be overlooked with these conclusions.

1) Comparing the system performances for different types of working fluids, it was revealed that the system performance is relatively insensitive to the selection of working fluid.

2) During the period of low solar radiation, the system with the heat pipe has shown uniform temperature distribution compared to the thermosiphon case. however, no appreciable differences are observed for the cumulative system efficiency.

3) The heat loss during nighttime seems substantial and provisions should be made to reduce this for better system performance.

4) Should the black-chrome coating be applied to our system in a more sophisticated manner, it will definitely improve its overall performance.

Some important aspects found here concerning the operational characteristics of heat pipes in connection with domestic solar water heaters will be further extended to develop more viable commercial design for the promotion of solar energy.

Ⅶ. ACKNOWLEDGMENTS

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Ⅷ. NOMENCLATURE

Φ = dimensionless temperature(for the heat pipe)

ϕ = dimensionless temperature(for water in the storage tank)

t = dimensionless time

ξ = dimensionless distance measured from the lower end of the heat pipe

η = cumulative system efficiency(dimensionless)

t^* = time constant(sec)(time required for the system with $0.186m^2$ of collector area and the accumulative system efficiency of 40%, to raise the water temperature for 32℃)

T = temperature(℃)

T_i = initial temperature of water in the storage tank(℃)

T_{ave} = average ambient temperature(℃)

q_{ave} = average solar radiation(W/m^2)

U_L = heat loss coefficient(W/m^2℃)

Ⅸ. REFERENCES

1. Abhat, A., "Performance Investigation of a Long, Slender Heat Pipe for Thermal Energy Storage Applications," J. Energy, Vol. 6, No. 6, 1982.
2. Richter, R. and Gottschlich, J., "Thermodynamic Aspects of Heat Pipe Operation," Proceedings of the AIAA/ASME 5th Joint Thermophysics and Heat Transfer Conference, Seattle, WA, 1990.
3. Tien, C.L. and Rohani, A.R., "Theory of Two Component Heat Pipes," J. of Heat Transfer, Vol 94, 1972.
4. Chi, S.W., Heat Pipe Theory and Practice, McGraw-Hill Book Company, Inc., New York, 1976.
5. Dunn, P and Reay, D.A., Heat Pipes, Pergamon Press, Ltd., New York, 1978.

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Abstract

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