DEVELOPMENT AND TESTING OF A COLLECTOR-CUM-STORAGE TYPE SOLAR WATER HEATER FOR DOMESTIC USE

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Technology in Agricultural Engineering

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679 573, MALAPPURAM

KERALA, INDIA

2000

DECLARATION

I hereby declare that this thesis entitled **"Development and Testing of a Collector-cum-Storage type Solar Water Heater for Domestic Use"** is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar tittle of any other University or Society

Tavanur

Er. BIJUKUMAR, K.

CERTIFICATE

Certified that this thesis entitled "**Development and Testing of a Collector-cum-Storage type Solar Water Heater for Domestic Use**" is a record of research work done independently by **Mr. Bijukumar, K.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Tavanur
10-7-2000

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BIJUKUMAR, K.

Dedicated to the Humanity

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SYMBOLS AND ABBREVIATIONS USED

AC	–	Alternating Current
Agric	--	Agricultural
Al	–	Aluminium
am	–	anti meridian
BC	–	Before Christ
C	–	Celsius
Cal	--	calories
cm	–	centimeter
DC	–	Direct Current
Dept.	–	Department
Dia.	--	diameter
Ed.	–	Edition
Engg.	--	Engineering
et. al.	–	and others
etc.	–	et. cetera
fig.	--	figure
FPM&E	–	Farm Power Machinery and Energy
GI	–	Galvanized iron
Govt.	–	Government
hr	--	hour
i.e.	–	that is
J.	–	Journal
J	–	Joules
K	–	Kelvin
KAU	–	Kerala Agricultural University
KCAET	–	Kelappaji College of Agricultural Engineering and Technology
kg	--	kilogram
kWh	–	kilo watt hour
kW/m^2	–	kilo watt per square metre
Ltd.	--	Limited
m	–	metre
M	–	Mega

Introduction

INTRODUCTION

Energy is defined in classical thermodynamics as the capacity to do work. It is the basic ingredient of all industrialized societies. Energy is currently derived from different sources such as oil, natural gas, coal, and wood. The known world reserve of coal has been estimated to range from 0.65 x 10^6 Mt to 1.16 x 10^6 Mt; assuming the present growth rate of 4% in production, the peak value in production is likely to be attained some where between AD 2030 and AD 2060, and that 80% of the amount could be consumed by AD 2250. Known oil reserves in 1993were estimated to be about 1000 billion barrels; with a steady rate of production at 20 billion barrels per year, most of the oil reserves would last only for another 50 years. The amount of natural gas reserves range from 85,000 to 90,000 billion m^3; since much of the gas is available in an associated form, it seems that the reserves of gas will last for the same period as crude oil. It is by now clear that the fossil fuel era of non-renewable resources is gradually coming to an end; oil being the first to deplete, followed by natural gas and coal. The availability of wood is also limited by deforestation and unfavourable climatic changes.

The energy problem is very serious in India. Inspite of important discoveries of oil and natural gas reserves, the import of crude oil continues to increase and the amount spent for it constitutes about 27% (as per 1996-'97 import expenditure) of our import bill. The coal reserves of India is estimated to be 1,93,800 Mt in 1992 with a proved reserves of 64,800 Mt. The coal production is expected to peak between AD 2040 and AD 2080, at the current rate of 7% increase in production. Our oil reserveswere estimated to be 758 Mt in 1990. The present domestic production cannot be sustained for more than 25 years.

Natural gas recoverable reserves in 1990 were 686 billion m^3. The stress for conserving energy and developing energy alternatives has led to considerable research and development work in this direction and significant progress has been made.

It is worth noting that man's large-scale use of conventional energy has led to a better quality of life; it has also created many problems; the harmful effect on the environment, serious air pollution due to combustion of fossil fuels, global warming, thermal pollution in lakes and rivers due to large amount of waste heat from power plants, being a few. So, for the survival of mankind we may have to shift our dependence on fossil fuel based life style to renewable energy and nuclear power based economy, but according to the researchers of the World Watch Institute "Societies reject nuclear power because of its economical, political and environmental liabilities and opt for renewable sources".

Solar energy shows promise of becoming a dependable energy source without new requirement of highly technical and specialized nature for its widespread utilization. Besides this, solar energy is abundant, totally pollution free, economically self sufficient, can be utilized for all purpose in all forms, has scope for decentralization, easy to use, needs minimum working expenditure, saves fossil fuel deposit, less hazardous, environmentally clean and available adequately in almost all parts of the world where people live.

The sun is the world's most abundant permanent source of energy. The amount of solar power intercepted by earth is 170 trillion kW, an amount 5000 times greater than the sum of all other inputs. Of this amount, about 30% is reflected to space, 47% is converted to low temperature heat and re-radiated to space and 23% powers the evaporation-precipitation cycle of the bio-sphere including about ½% representing the kinetic energy of the winds and waves and photosynthetic storage in plants. The intensity of electromagnetic radiation is 1.94 $cal/cm^2/min.$ or 1.353 kW/m^2 on a surface normal to the solar beam; this average value of solar radiation outside the earth atmosphere is known as solar constant. It is further diluted by local weather phenomena and air pollution; and the peak clear sky solar intensity available on a horizontal surface is $1kW/m^2$. The integrated daily average could be as high as 6 to 8 $kWh/\ m^2$. This would give an idea of tremendous amount of energy incident on the surface of the earth.

Being a tropical country, India receives a large amount of solar energy than many parts of the world, for most part of the year. In most parts of the country sunshine is available for over 250 to 300 days, i.e. 2000 to 3200 h/year. The level of both global and diffuse radiation in India is high. The annual global radiation varies from 1600-2200 kWh/m^2 and diffuse radiation from 730-925 kWh/m^2. The global solar radiation during the summer months ranges from 120-220 $kWh/m^2/month$ and 60-180 $kWh/m^2/month$ during winter. The diffuse radiation varies from 30-100 $kWh/m^2/month$. The total solar radiation varies from 5-7 $kWh/m^2/$ day in sunny regions.

The total solar energy received in India is about 6000 million MWh/year. Assuming that about 1% of this energy can be tapped at about 10% efficiency, the total potential of solar energy works out to be 6000 trillion Wh/year. This is equivalent to about 35 times the present electricity generation in India.

There are three approaches for the utilization of solar energy:

i) low grade solar heating (temperature below 100^0C)

ii) high grade solar heating

iii) direct conversion to electricity.

Solar energy now makes its biggest impact in domestic water heating and space heating. The two approaches to convert sunlight to heat are passive systems and active systems. A passive system may be defined as one in which the energy and mass flow is by natural means (involving conduction, convection, radiation or evaporation). An active system is one in which all the mass flow is by forced means (involving fans or pumps). A hybrid system is one in which at least one of the significant flows is by natural means and at least one by forced means.

Water heating is one of the simplest applications of solar heat and is the least expensive. The demand of hot water is relatively constant throughout the year. Solar water heating is one of the most common, easier and more practical utilization of solar energy for applications up to 60 to 70^0 C of water temperature; it has excellent life cycle-cost characteristics, since water heating loads are rather uniform year-round compared to space heating loads and the payback in fuel saving is therefore more favourable than for space heating systems. So solar heating at this moment is one of the most attractive applications from an economic standpoint. It is most viable of all low temperature solar energy utilization technologies. In many countries of the world, it is already competing on equal terms with systems using other energy sources.

Flat plate collectors can be designed for applications requiring energy delivery at moderate temperature, up to perhaps 100^0C; they have the advantages of using both beam and diffuse radiation, requiring no maintenance, no orientation towards the sun and no costly mechanical parts.

Solar water heaters employing flat plate collectors can be divided into three types:

i) domestic solar water heaters; in which the storage tank and absorber are separate and water is circulated by natural circulation.

ii) large size solar water heaters; designed for community use such as in hotels, hostels, hospitals etc.

iii) built-in-storage type solar water heaters; designed with a view to reduce cost.

Flat plate collector-cum-storage type solar water heaters are highly efficient, due to direct contact of water with the absorber plate, and the absence of pipes between the collector and storage tank. Solar water heating devices are already developed, but they are not yet popularized, due to high heat loss from the system; mainly because of high thermal conductivity of the materials commonly used, like MS having a thermal conductivity of 46.10 cal/hcm^{0}C. This defect can be controlled by using materials of low thermal conductivity, like fibre glass for storage tank. The thermal conductivity of fibre glass is 0.0196 cal/hcm^{0}C.

In countries like India, 20% of the energy is used for domestic purposes, of which cooking is most important. The population of India is about 90 crores (as per 1991 census) and the quantity of water required for cooking process is 4.5 liters/head/day. Let water-be supplied at normal ambient temperature of 25^0C, then the energy required to raise the temperature of water to 100^0C for cooking purpose comes around $3.533 x 10^8$ kWh. If we can supply water at a temperature of 70^0C, by utilizing flat plate solar water heaters, then the energy required for cooking can be saved up to $2.21 x 10^8$ kWh.

The present study is aimed to design and develop a collector-cum-storage type solar water heater of 30 litre capacity to supply hot water for a family of six members, using material of less thermal conductivity i.e. fibre glass.

Objectives of the study

1. To design and develop a collector-cum-storage type solar water heater of 30 litre capacity.
2. To evaluate the performance of the water heater for domestic use.
3. To optimize the heater parameters for best operating conditions.

Review of Literature

REVIEW OF LITERATURE

2.1 History

The first person known to have used thc sun's energy on a large scale is Archimedies, who repeatedly set fire on an attacking Roman fleet at Syracuse in 212 BC. The studies on the sun and its potential began in the 17th century, when Galileo and Lavoisier utilized the sun in their research. The solar liquid heater was invented by N.D. Saussure, a Swiss naturalist, during the second half of the 17th century.

Modern scientific research in the utilization of solar energy commenced in 1885 when C. Guntur, an Australian, invented a solar boiler using mirrors. Herschel (1837), a German, and Tellier (1885) also experimented with solar water heater. Even in earlier times the people of Africa, Australia, the Arab countries, China, India, and Pakistan used their ingenuity in heating water by placing a specially shaped copper pot filled with water, in the sun during the winter.

In the later half of the last century and during the first half of this century, progress in the field of energy research was fairly slow, due to availability of cheap fossil fuels. The waning solar energy research was revived in 1940 when Godfray L. Cabot left a large sum of money for research project at the Massachusetts Institute of Technology, then a team of engineers, under the direction of Dr. Hottel began to study the performance of solar collectors for fluid heating systems. In 1942 Dr. Hottel and Wortz published the first scientific paper on flat plate collectors. The solar water heating industry flourished during the 1940's and 1950's in Southern Florida. In the Miami area alone more than 60,000 water heaters might have been installed during this period.

During the recent energy-panic research, the utilization of solar energy has gathered considerable momentum, especially in industrialized countries such as U.S.A, Russia, France, Australia, and Canada.

2.2 Terminologies commonly used in solar energy field

Absorptance : The ratio of the radiant energy absorbed by a plane surface to the radiant energy incident upon that surface.

Absorption : The process by which radiation is converted within a material into excitation energy.

Absorption Coefficient : A measure of the absorbing strength of a material for radiant energy per unit area. Usually expressed as a decimal and denoted by $\propto$.

Altitude : The angle which the rays of the sun makes with the horizontal plane of any given point on the surface of earth.

Azimuth : The angle measured at any given point on the earth's surface between the horizontal component of the sun's rays and the meridian passing through that point.

Black body : This describes an ideal substance which absorbs all radiation falling upon it and emits nothing. An alternative definition : a body which emits the maximum possible radiation, i.e. its emissivity is 1.

Declination : The angle between the plane of the earth's orbit and the equatorial plane; or the angular distance of the sun from the equator.

Diffuse solar radiation : The scattered radiation falling on a plane of stated orientation over a stated period from the sky, and in the case of an inclined surface, reflected from the ground as well.

Direct solar radiation : The radiation from the sun falling on a plane of stated orientation over a stated period received from a narrow solid angle centered on the sun's direction.

Emittance : The ratio of the radiant energy emitted (in the absence of incident radiation) from a given plane surface at a given temperature, to the radiant energy that would be emitted by a perfect black body at the same temperature.

Flat-plate collector : Any non-focusing, flat surfaced solar heat collecting device.

Hour angle : The angular distance of the sun from its position at noon.

Inclined surface : A surface or solar collecting device tilted at an angle to the horizontal plane or to the observer's horizon.

Insolation : The solar energy incident on a unit area of surface over a period of time; the time integrated solar irradiance.

Insulation : Thermal wrapping or lagging applied to a heat store or pipe to reduce heat loss or to protect against frost.

Irradiance : The radiant energy falling per unit area on a plane surface per unit time, normally stated in W/m^2.

Latitude : The latitude of a point on the earth's surface is its angular distance from the equator.

Net radiation : The difference between total incoming and total outgoing radiation.

Radiant flux : Radiant flux is the power emitted, transferred, or received in the form of radiation.

Reflectance : The ratio of radiant energy reflected from a surface, to the radiant energy incident upon that surface.

Selective surface : A surface, which has high absorbance for incident radiation (wavelengths less than 1000 nm) and high reflectance (low absorbance) in the infra-red range (wavelengths greater than 1000nm).

Solar collector : A solar collector is a device designed to absorb incident solar radiation and to transfer the energy to a fluid passing in contact with it.

Solar constant : The intensity of solar radiation outside the earth's atmosphere at the mean distance between the earth and the sun. It equals to about 1.353 kW/m^2.

Solarimeter : Instrument for measuring the solar irradiance, including both direct and diffuse components. Mounted horizontally it will measure global irradiance.

Solar noon :For any location solar noon is the local time at which the sun is at its highest altitude.

Thermosyphon : A circulating system where a circulating pump is not used. Hot water being less dense than cold water, rises to the top of the system and is replaced by cold water, in the process setting up a natural circulation of water through the system.

2.3 Classification of solar energy utilization

The energy from the sun can be used mainly in two ways:

i) direct methods ii) indirect methods

i) **Direct methods**

In direct methods, solar radiation falling from the sun is utilized directly for the generation of energy. The four principal methods for the conversion of solar radiation into energy are usually distinguished as:

a) Thermal conversion – achieved by solar collectors

b) Photo-voltaic conversion – achieved by solar cells

c) Photochemical conversion – achieved by liquid solar cells

d) Biological conversion – called photosynthesis.

ii) **Indirect methods**

Indirect solar energy utilization methods are,

a) Water power

b) Wind

c) Bio-mass

d) Wave energy

e) Ocean temperature difference

2.3.1 Thermal conversion – collection and storage

The principle in any collection device is to expose a dark surface to solar radiation so that radiation is absorbed. Solar collectors are heat exchangers designed to absorb solar radiation and to transfer the energy to a fluid passing in contact with it. A collector will usually use either a liquid or a gas as the transfer fluid. The most common liquid is water or a water-ethylene glycol solution, the most common gas is air.

Collectors can be classified into three groups:

i) Flat-plate collectors

A non-concentrating or flat-plate collector is one in which the absorbing surface for the solar radiation is essentially flat with no means for concentrating the incoming solar radiation. They are generally stationary and their outlet temperature capacity is below 100^0C. Heat losses must be minimized to get higher temperature. Evacuated tube collectors are used for this purpose. These can reach up to 140^0C. Flat-plate collectors are commonly used for space heating, swimming pool heating, and domestic hot water applications.

ii) Concentrating (focussing) collectors

A concentrating or focussing collector is one which track the sun and can generally utilize only the direct radiation, contains reflectors or employs other optical means to concentrate the energy falling on the aperture on to a heat exchanger of surface area smaller than the aperture. They are capable of producing higher temperatures.

iii) Non imaging concentrating collectors

Non imaging concentrators come in between flat-plate collectors and concentrating collectors. These collectors do not produce a well defined focal spot and are capable of achieving temperatures up to about 175^0C. These systems require no tracking if their concentration ratio (ratio of aperture to absorber area) is below 1.7 and require only seasonal adjustments at concentration ratios up to 5.

2.3.1.1 Materials for collector components

The three main parts of a collector are the cover, the absorber, and the insulated back. The materials employed for these three main parts largely determine both the efficiency and its cost, and thus the economic attractiveness.

i) Cover materials

The ideal cover (glazing) material of a collector should,

a) transfer the whole incident radiation

b) be opaque to the infra-red radiation emitted from the absorber

c) minimize the external heat exchanges by conduction or convection; that is, have low coefficient of thermal conductivity

d) have good mechanical resistance; be suitable for integration in a light structure, and have durability and low price.

ii) Absorbing materials

The absorbing material must

a) absorb maximum incident solar radiation (0.3 to 3μm)

b) emit minimum infra-red radiation

c) have great thermal exchange with the heat transfer fluid

d) have good durability for a low price.

iii) Insulation materials

The insulating material should have

a) very low thermal conductivity

b) high resistance to humidity

c) good mechanical resistance

d) fire proof and low price.

2.3.1.2 Thermal energy storage

The intermittent, variable and unpredictable nature of solar radiation is the major problem associated with the utilization of solar energy, which generally leads to a mismatch between the rate and time of collection of solar energy and the load needs of a thermal application. Thus it is necessary to use a storage system in between. The purpose of such a system is to store it when available in excess and to use it when the supply of solar energy is inadequate. The size of the storage system is largely determined by the specific purpose for which it is used.

Energy storage can be in various forms – thermal, electrical, mechanical or chemical. Thermal energy can be stored as sensible heat or as latent heat. Sensible heat is usually made use of an insulated container, having a liquid like water or a porous solid in the form of pebbles or rocks. This type is preferred with liquid collectors, while the other type is compatible with air heaters. In case of latent heat storage, heat is stored in a substance when it melts and extracted when the substance freezes. Sensible heat storage systems operate over a range of temperatures, while latent heat storage systems operate essentially at the temperature at which the phase change takes place.

2.4 THERMAL APPLICATIONS

The important fields of thermal application of solar energy are explained below:

2.4.1 Solar water heating

Solar water heating is one of the direct use of solar energy that has been practised most extensively in the last two decades. It is the most viable of all low temperature solar energy applications.

Different types of solar water heaters are designed and constructed during the course of solar heater development. One of the methods of classifying solar water heating systems divides them into two, namely:

i) direct systems ii) indirect systems

2.4.1.1 Direct systems

Direct systems are those in which potable water is heated directly in the solar collector.

Direct systems are divided into

i) Unsheltered heaters
   a) Bare trough on the ground
   b) Bare trough off the ground
   c) The black bag
   d) Black sack with bottom insulation
ii) Sheltered heaters
   a) Sheltered black sack
   b) Metal plate collector with moving fluid
   c) Collector-cum-storage type

iii) Selective surface

iv) Evacuated collectors

v) System with separate storage

a) Natural convection solar water heaters

b) Forced circulation water heaters.

i) Unsheltered heaters

a) Bare trough on the ground

This is the simplest possible water heater and is shown in Fig.1(a). A trough of water resting on the ground is exposed to the sun. An outdoor swimming pool is an example. On a hot sunny day the water is warmed up, but the temperature rise is limited by the ease with which the heat is lost to the ground and by evaporation.

b) Bare trough off the ground

Supporting the trough off the ground decouples the heat sink as shown in Fig.1(b). But the heating is still severely limited by low absorptance of water. More over heat loss by evaporation and convection takes place here also, thus the temperature rise is less.

c) The black bag

Here the water is enclosed in a shallow mat-black bag. Usually it is placed on a roof as shown in Fig.1(c). So no heat is lost by evaporation. The black outer surface absorbs radiations much better than transparent water. A part of this heat then passes to the water inside by conduction. This type of heater is cheap, easy to make and gives moderately hot water upto 45^0C. Heat loss by forced convection severely limits the performance. Another problem is that many cheap black, water proof materials degrade in sunshine and cease to be water proof with in a few months.

d) Black sack with bottom insulation

The heat loss in the above system can be almost halved by simply insulating the bottom of the collection device, as shown in Fig.1(d). Almost any material that traps air in small holes (≤ 1 mm) is useful as an insulator, e.g. fibre glass, expanded polystyrene or wood shavings.

ii) Sheltered heaters

a) Sheltered black sack

Placing the bag in an open sunny location usually exposes it to cooling breezes. The bag can be sheltered from the wind by placing it in a cover box with a transparent lid, as shown in Fig.1(e). Glass is the best material for this purpose. Clear polythene sheet is cheaper initially, but has to be replaced very freqùently, as it disintegrates in sun light.

b) Metal plate collector with moving fluid

In the plate and tube collector, water is confined in parallel tubes which are attached to a black metal plate, as shown in Fig.1(f). It is essential to have a low thermal resistance between the plate and tubes, and across the plate between the tubes. The plate and tubes are sheltered from the wind in a box with a glass top. Typically the tube is of 2 cm dia., tube spacing 20 cm and the plate thickness 0.3 cm.

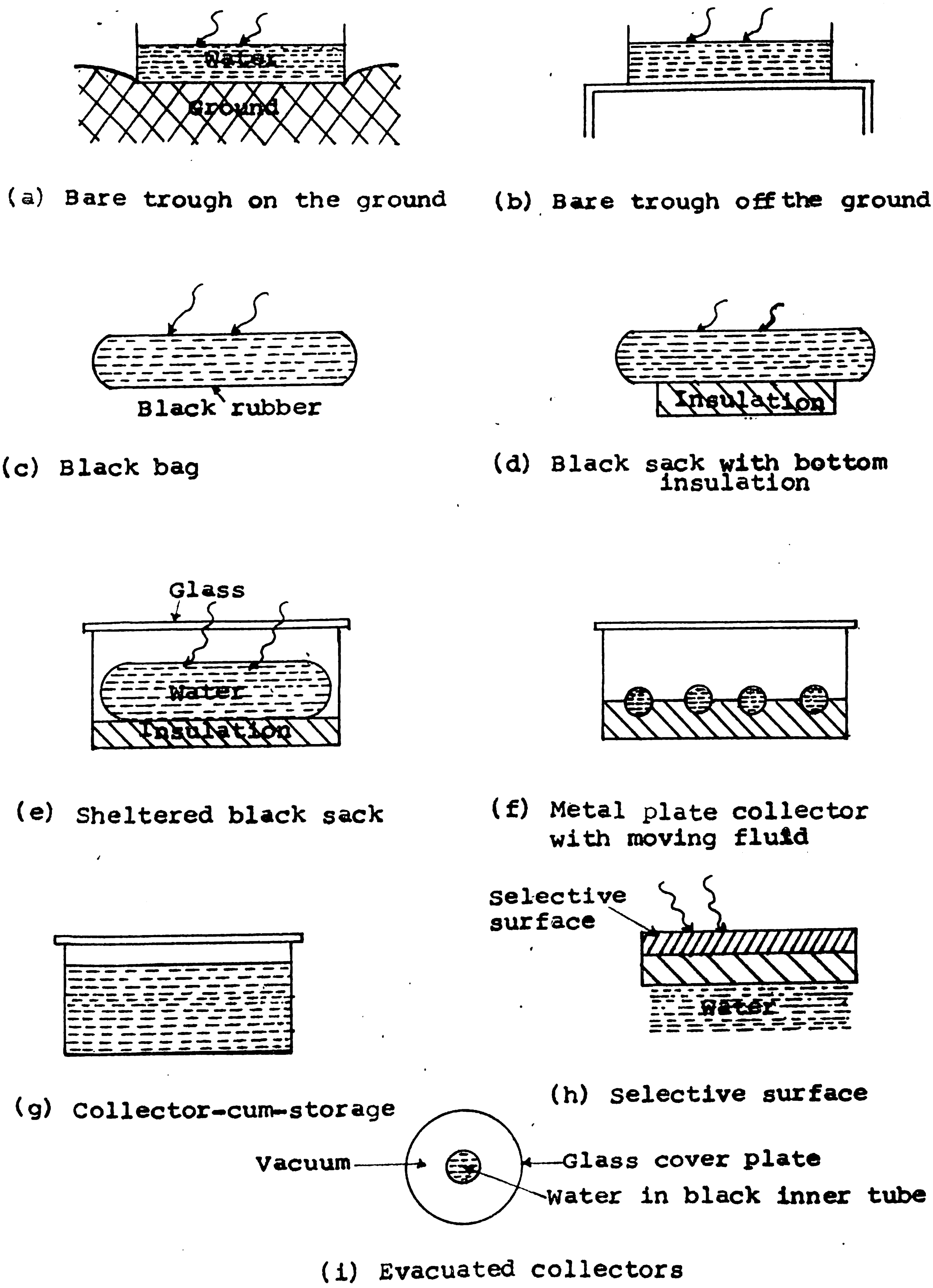


Fig. 1 CLASSIFICATION OF SOLAR WATER HEATERS

c) Collector-cum-storage type

This type of solar water heater incorporates storage volume and collector in a single unit and is shown in Fig.1(g). These collectors are potentially more efficient than tube collector because of increased thermal contact area.

iii) Selective surface

This type of collector shown in Fig.1(h), would maximize its energy gain and minimize its energy loss, by having a high monochromatic absorptance at 0.5μm and low monochromatic emittance at 10μm. A solar collector absorbs radiations of wave length around 0.5μm (from a source of 6000^0K) and emits radiations at wave length around 10μm (from a source of 350^0K). Therefore an ideal surface for a collector would maximize its energy gain and minimize its energy loss, by a high monochromatic absorptance $\alpha\lambda$ at $\lambda \approx 0.5\mu m$ and low monochromatic emittance $\varepsilon\lambda$ at $\lambda \approx 10\mu m$.

iv) Evacuated collectors

It is necessary to reduce the convective losses to obtain higher temperature (above 100^0C). One way is to use extra layers of glass above a flat plate collector. A method that is better but technically more difficult is to evacuate the space between the plate and its glass cover as shown in Fig.1(i).

v) System with separate storage

a) Natural convection or thermosyphon solar water heaters

This consists of a tilted collector, with transparent cover plate, a separate highly insulated water storage tank and well insulated pipes connecting the two; it is shown in

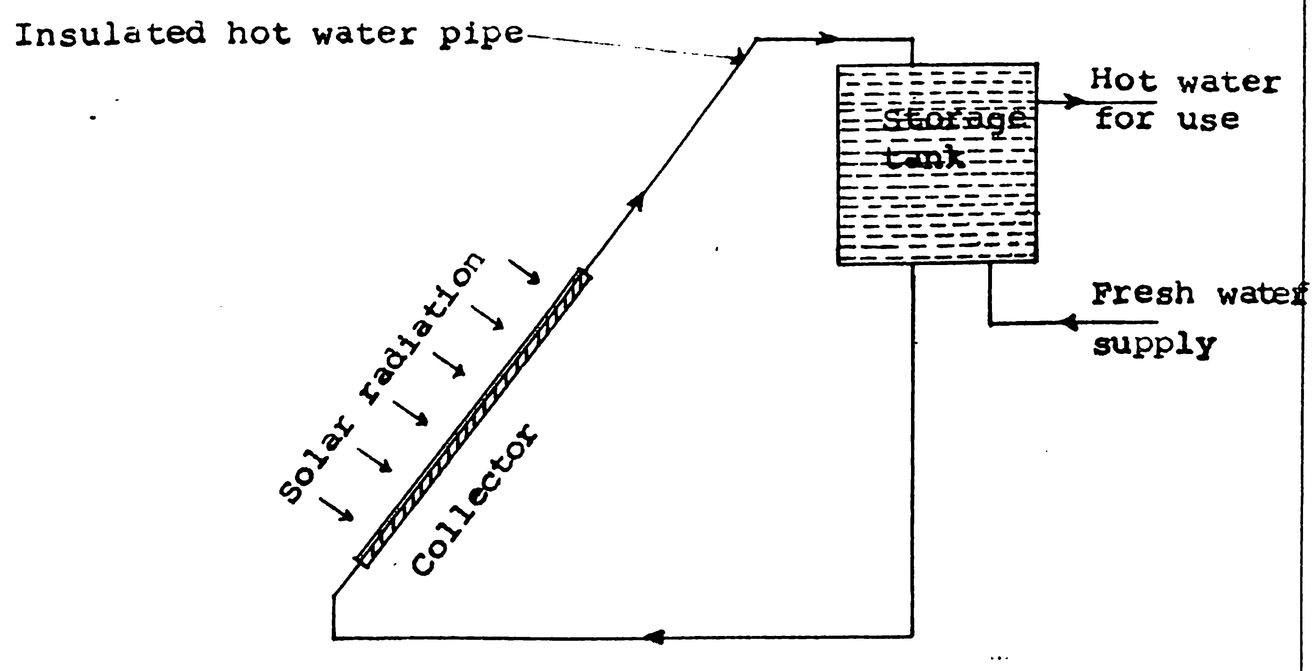
Fig.2(a). No auxiliary energy is required to circulate water through it. Circulation occurs through natural convection or by thermosyphoning. When water in the collector is heated by the sun, it expands (becomes less dense) and rises up the collector, and then through a pipe into the top of the storage tank. This forces cooler water at the bottom of the tank out through another pipe leading to the bottom of the collector. After sunset, a thermosyphon system can reverse its flow direction and lose heat to the environment during the night. This may be prevented if the top of the absorber plate is at least one foot below the cold leg fitting on the storage tank. An electrical immersion heater can be used as a backup for this system, to provide heat during long, cloudy periods.

b) **Forced circulation water heaters**

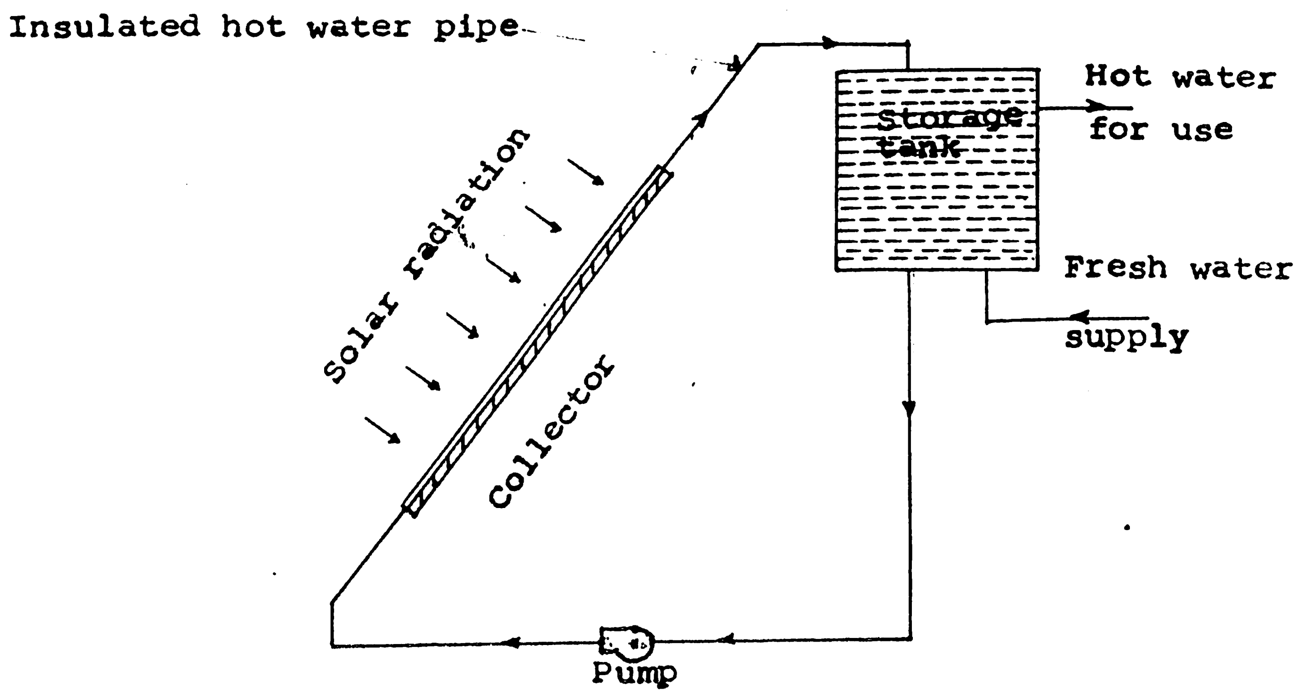
Solar water heating systems necessitating the use of a pump for a forced fluid flow in the collector, is termed as forced convection system. A typical system is shown in Fig.2(b). There is no requirement for locating the tank above the collector. The additional components would include a motor and a pump with controller (a differential thermostat), between tank and collector. A check valve is used to prevent reverse circulation and resultant thermal losses from the collector at night.

2.4.1.2 Indirect solar water heating system

Indirect systems are those in which a separate heat transfer medium is used in the solar collector loop and potable water is heated indirectly by a heat exchanger. This system uses a non freezing fluid in the solar collector loop for heat collection. Heat is then transferred from this fluid to potable water in a heat exchanger to the storage tank. It is shown in Fig.3. The additional cost of these components usually offsets the fact that,

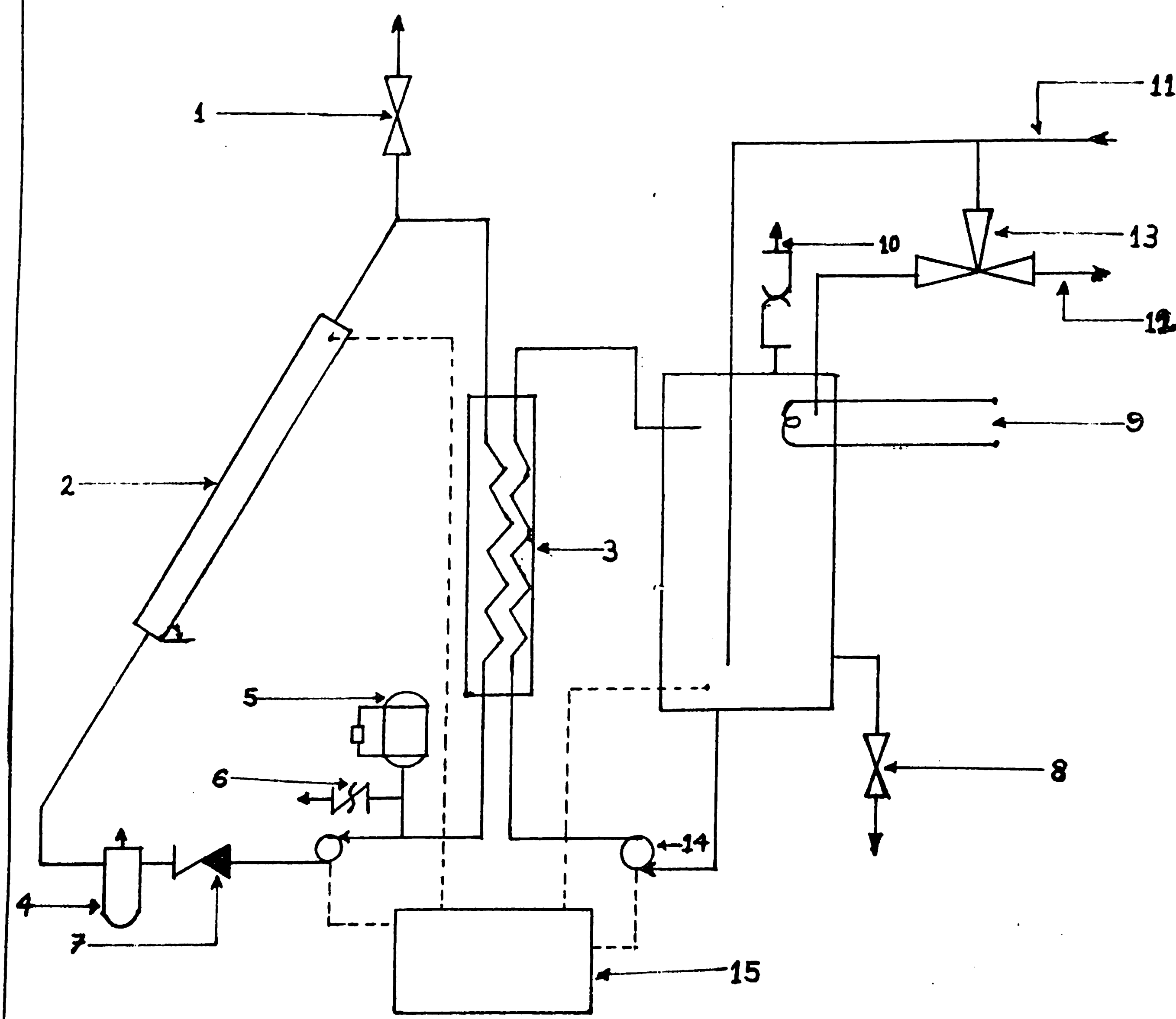


(a) Schematic diagram of a thermo-syphon solar water heater



(b) Schematic diagram of a forced circulation solar water heater

Fig. 2 SOLAR WATER HEATERS WITH SEPARATE STORAGE



1. Air bleed
2. Collectors
3. Heat exchanger
4. Filter/strainer
5. Expansion tank
6. Safety valve
7. Check valve
8. Drain
9. Heating element
10. Safety valve
11. Cold water
12. Hot water
13. Tempering valve
14. Pump
15. Domestic hot water control

Fig. 3 SINGLE TANK INDIRECT SOLAR WATER HEATING SYSTEM freeze protection is guaranteed under all conditions, including power failure. The most commonly used antifreeze liquid for solar application is ethylene glycol. To prevent internal corrosion of the surfaces in the case of open type of solar panel, especially if aluminium is used in the construction, a corrosion inhibitor such as sodium nitrate or benzoate, should be added and is available with the antifreeze in a ready mixed form.

2.4.2 Solar space heating

Space heating is of particular relevance in colder countries where a significant amount of energy is required for this purpose. The heating of residences by the use of solar radiation is a very ancient concept. Virtually all solar heating systems fall into two primary categories. The first is passive systems, in which solar radiation is collected by some elements of the structure itself, or admitted directly into the building through large, sun-facing windows. The second one is the active systems, which generally consist of, (a) separate solar collectors, to heat either water or air, (b) storage device, which can accumulate the collected energy for use at nights and during clement days, and (c) a back up system to provide heat for protracted periods of bad weather. Heat is transferred for warming the living spaces of building from the collectors or from the storage, by means of conventional equipment such as fan coil units, when hot or cold water is provided; fan, ducts, and outlets when the heat transfer medium is air, and radiant means when heating is the only task which must be accomplished.

2.4.3 Solar space cooling

Solar cooling of buildings represents a potentially significant application of solar energy for building air conditioning for most sunny regions of the world. An advantage over solar space heating is that the demand for cooling occurs mostly at the time when solar energy is available. A wide spectrum of physical, chemical and electrical processes can be employed for air conditioning of buildings. All these processes can be integrated in either a closed or an open cycle. Since the energy of the sun is being received as heat, the obvious choise is a system working on the absorption refrigeration cycle which requires most of its energy input as heat.

2.4.4 Salt production by evaporation of sea water or inland brines

Solar evaporation is the historical and traditional method of obtaining salt from sea water or brines. Modern developments have been concerned mainly with improved pond construction and harnessing.

2.4.5 Solar distillation

Solar distillation can prove to be an effective way of supplying drinking water to communities where the natural supply of fresh water is inadequate in comparison to the availability of brackish or saline water. The basic method of solar distillation is to admit solar radiation through a transparent cover to a shallow, covered brine basin; water evaporates from the brine, and the vapour condenses on the covers which are so arranged that the condense flow therefrom into the collection troughs and then into a product-water storage tank.

2.4.6 Solar drying

One of the traditional uses of solar energy has been for drying agricultural produces, done in open ground. Drying can be done in a faster and in a controlled fashion by using dryers; in addition, a better quality of produce is obtained. A cabinet type solar dryer is suitable for small scale use. Solar radiation entering the enclosure through the transparent cover, is absorbed in the product itself and the surrounding internal surfaces of the enclosure. Temperature ranging from 50^0C to 80^0C is usually attained and the drying time ranges from 2 to 4 days. For large scale drying, a convective drier is used, in which the solar radiation does not fall on the produce to be dried, instead air is heated separately in a solar air heater and then ducted to the chamber in which the produce to be dried is stored. Generally forced circulation is used.

2.4.7 Solar cooking

Solar cooker designs generally fall into two categories; the first is the box type cooker which essentially consists of a rectangular enclosure, insulated on the bottom and sides, and having one or two glass covers on the top. Solar radiation enters through the top and heats up the enclosure in which the food to be cooked is placed in shallow vessels. The second category are those in which the radiation is concentrated by a paraboloid reflecting surface. The cooking vessel is placed at the focus of the paraboloid mirrors and is thus directly heated. These cookers require some form of tracking. Temperature well above 200^0C can be achieved in such cookers.

2.4.8 Solar engines for water pumping

The solar pump is not much different from a solar heat engine working in a low temperature cycle. The source of heat is the solar collector and the sink is the water to be pumped. The primary components of the system are an array of flat-plate collector and a Rankine engine with an organic fluid as the working substance.

2.5 Photo-voltaic conversion

The photo-voltaic effect is defined as the generation of an electromotive force as a result of the absorption of ionizing radiation. The device used in photo-voltaic conversion are called solar cells. Solar radiation falling on the device is converted directly into DC. The principal advantages associated with solar cells are that they have no moving parts, require little maintenance, and work quite satisfactorily with beam and diffuse radiation. Also they are readily adapted for varying power requirements because a cell is like a building block. The main limiting factor is their exorbitant cost and consequently such installations are uneconomical.

2.6 Thermal losses in flat-plate collectors

The performance of a solar collector is discribed by an energy balance that indicates the distribution of incident solar energy into useful energy gain and various losses. The thermal losses can be separated into three:

i) Conductive losses

Conduction through the back and sides of a collector is usually negligible if the back and sides of the collector are well insulated. An overall heat transfer coefficient value of 0.69 $W/m^2\,{}^0K$ is suggested to minimize back losses.

ii) Convective losses

Convective losses occur from the absorber plate to the environment through intermediate convection exchange between the air enclosed in each insulating zone and the boundaries of each zone, and between the collector covers. Sizing of the air gap between the collector covers at 1.25 to 2.5 cm reduces internal convection losses to a minimum possible level. In the absence of wind, external convection loss from the outermost cover is by the mechanism of natural convection; but even in low winds, forced convection occurs and the loss increases substantially.

iii) Radiative losses

Radiative losses from the absorber can be reduced by the use of spectrally selective absorber coating, which decreases heat losses and increases collector efficiency.

2.7 Status of solar energy in India

India receives around 6000 million MWh of solar energy per year, at a rate of 5 to 7 kWh/m^2/day for 250 to 300 days in an year. The distribution of global solar radiation is shown in Fig.4, and the sunshine hours in Fig.5. In view of the tremendous potential for harnessing New and Renewable Sources of Energy (NRSE) in India, the Govt. of India, Ministry of Non-Conventional Energy Sources (MNES) revised its proposed targets for harnessing various forms of NRSE during its five year plans. The 8th plan envisages a capacity addition of around 2000 MW from NRSE.

India has tremendous potential for solar thermal systems for water heating, space heating and cooling, desalination, drying, refrigeration, and power generation. A solar thermal power plant of about 30 MW is proposed to be established as a demonstration project by the Govt. of India in Rajasthan.

Solar water heating systems and solar cookers have already been commercialized in India. Recently, a high performance solar hot water system using UTR 371 ETC

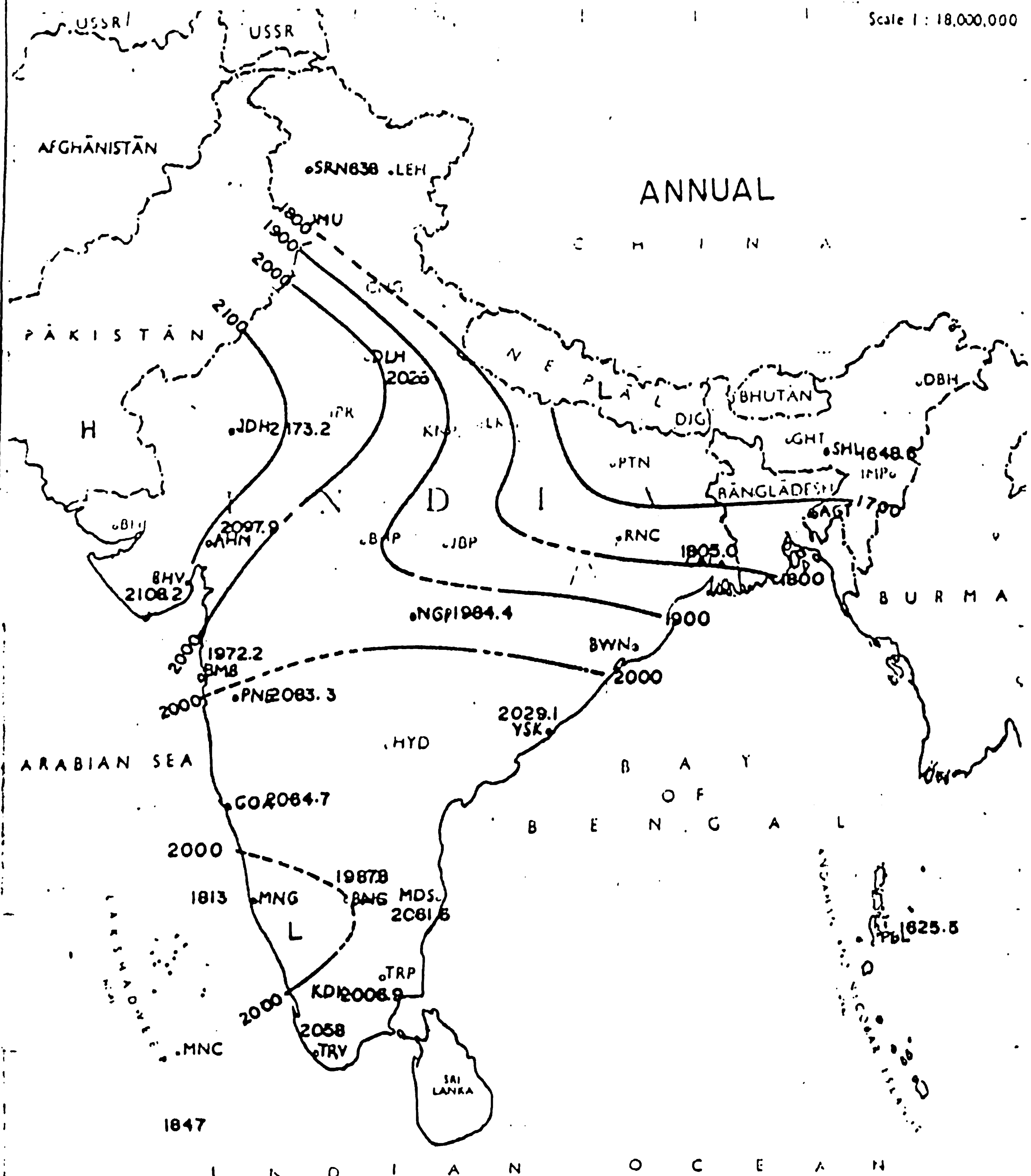


Fig. 4. DISTRIBUTION OF SOLAR GLOBAL RADIATION - ANNUAL

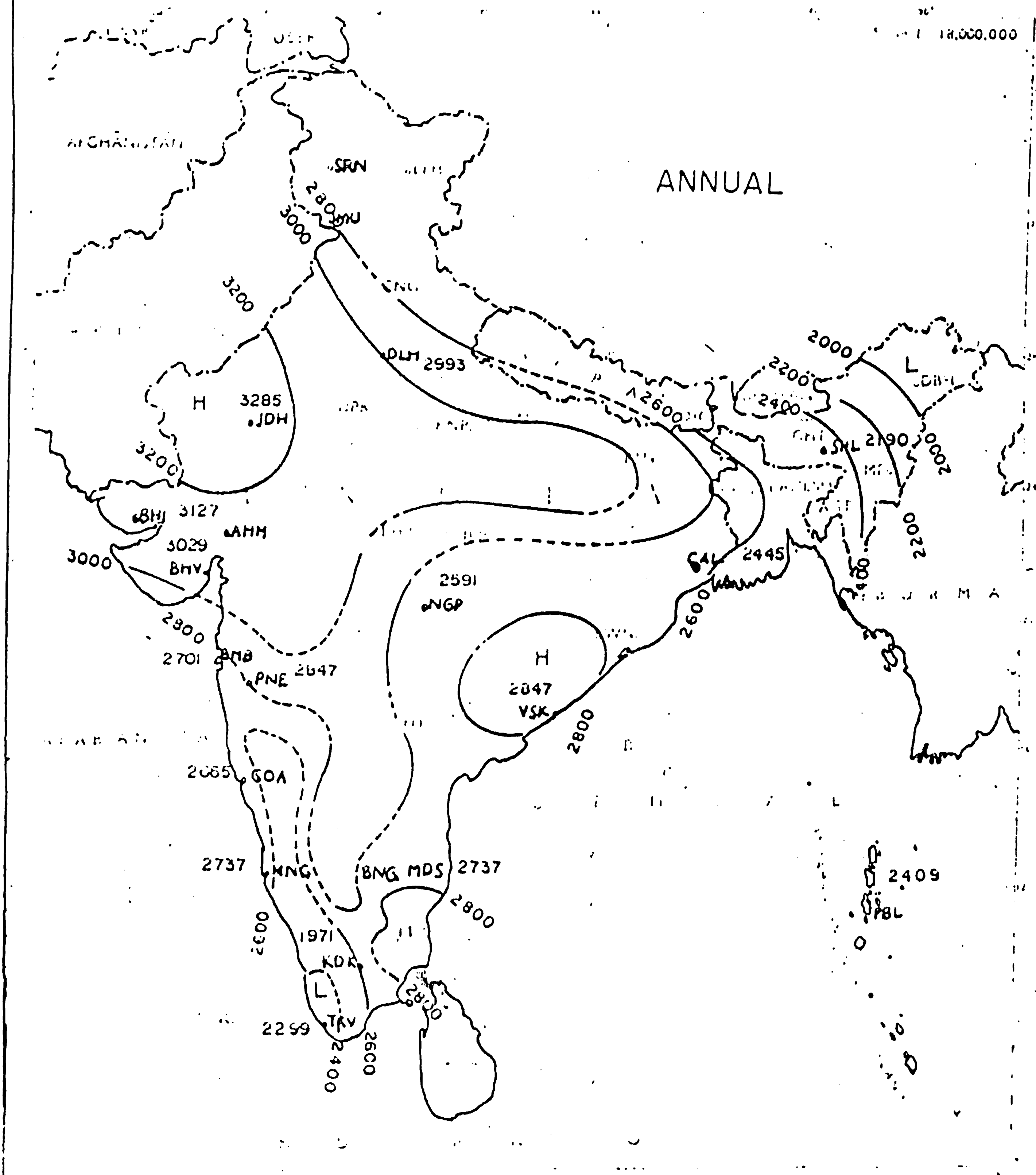


Fig. 5. DISTRIBUTION OF HOURS OF SUNSHINE - ANNUAL

(Evacuated Tubular Collector) has been installed at Madras. The system can supply 3000 litres of hot (80^{0}C) water per day. Solar hot water systems are now being manufactured by over 30 firms in our country.The technology for the manufacture of the solar hot water systems has been developed under the R&D programmes of Dept. of Non-conventional Energy Sources (DNES) by various organizations and private industries. The products are in many cases standardized by the Bureau of Indian Standards (BIS). Product innovation and cost reduction have to be carried out in order to make thermal devices market oriented.

The approximate installed capacity as on 30-03-1996 was

a) Solar thermal systems – 6,50,000 sq. mtrs.

b) Solar cookers – 5,00,000 nos.

c) Solar crop drying units – 90 nos.

d) Solar timber kilns – 95 nos.

e) Solar distillation units – 25,000 nos.

f) SPV water pumping units – 50,000 nos.

Solar Photo-Voltaic (SPV) systems have two distinct market segments in India; the first is the Govt. sector and the second one is commercial in nature being mostly used for meeting essential load requirement for data logging, telecommunications, transmissions, and for various applications in railways etc. Rural and tribal villages of India have an estimated potential requirement of 80 million solar PV lanterns.

Solar photo-voltaic pumping systems have been found successful for shallow well pumping in rural areas. The high initial cost of the system prevents large scale applications. SPV systems with a PV array capacity of 500 to 900 watts, and DC/AC submersible pumps have been successfully tested by a few manufacturers. About 50,000 SPV water pumping systems were installed in the country by 1997.

For solar energy studies the stations selected by DNES are Ahamedabad, Bangalore, Mumbai, Calcutta, Goa, Jodhpur, Kodaikanal, Chennai, Mangalore, Nagpur, Nandihills, Puna, PortBlair, Shillong, Trivandrum, and Vishakhapatanam. In Kerala the Agency for Non-conventional Energy and Rural Technology, Trivandrum has installed solar water heaters having various capacities at different parts of the State.

2.7 Work done on solar energy conversion systems

Thrust on solar energy increased in our country, when we faced the energy crisis, with the frequent wars in the Gulf regions and imperial control by the Western countries on petroleum products in the Gulf region. Hence, in a number of technical institutes, research works on solar energy were conducted and use of solar energy has been encouraged. Some of the research organizations like Central Institute of Agrl. Engg; Bhopal, Punjab Agrl. Univerrsity; Ludhiana, Haryana Agrl. University; Hissar, Tata energy Research Institute; New Delhi, Indian Institute of Technology; New Delhi, Central Arid zone Research Institute; Jodhpur, Tamil Nadu Agrl. University; Coimbatore, Indian Institute of Technology; Kharagpur, etc were actively involved in developing solar heaters for rural areas. Some of the important works conducted all over the world are discussed below:

2.8.1 Work done in India

Garg, H.P. (1975) designed a built-in-storage type solar water heater and prototype tested in Jodhpur. The heater consisted of a rectangular, 20 gauge GI tank measuring 112x80x10 cm with a capacity of 90 litres. It was contained in a MS box with 5 cm layer of fibre glass insulation below it and one glass cover on the top. The front face of the tank was blackened by lamp black paint. He concluded that this heater could supply 90 litres of water at a mean temperature of 50-60^{0}C in winter and 50-70^{0}C in summer and monsoon seasons.

Nahar, and Malhotra (1981) developed and tested a low cost cylindrical collector-cum-storage type solar water heater. The dimension of the heater was 1m length and 0.25 m diameter and was made from 20 gauge GI sheet. Outer surface of the cylindrical tank was painted by black board paint and two glazing covers of PVC film of 0.2 mm thickness were provided on it. This heater could deliver water at a temperature of 50-55^{0}C in the winter afternoons when tap water temperature was as low as 18^{0}C.

Bansal (1981) conducted studies on collector-cum-storage solar water heaters and concluded that these could meet the hot water requirements for a variety of applications.

Garg, H.P. (1982) developed a built-in-storage type solar water heater of new design, the exposed side of the tank was blackened by blackboard paint. It consisted of a rectangular 20 gauge GI tank measuring 112x80x10 cm and having a capacity of 90 litres of water. The heater was inclined at an optimum angle, which was 43^0 from horizontal for Delhi, and was oriented due south to collect maximum radiation.

Nahar (1983) designed an improved collector-cum-storage type solar water heater for year round performance. It consisted of a 20 gauge GI tank with dimensions of 115x90x10 cm and had a capacity of 100 litres of water. The tank was encased in an MS tray with 100 mm insulation at the back and on the sides; and two glass covers, at an optimum air gap of 40 mm, were fixed at the top. The heater was of the non-pressure type and worked on the push through system. This improved solar water heater could provide hot water throughout day and night at a temperature of 40^{0}C.

Singh (1985) developed a built-in-storage type solar water heater having a work capacity of 100-200 litres of hot water at 55-60^{0}C per day. The water tank was made of 18 gauge GI sheet. The top surface of the tank was painted with non-glazy black paint had double transparent glass shield. The efficiency of the system was found to be 40-42 %.

Anonymous (1986) developed a low cost and fairly efficient water heater of built-in type. It consisted of a rectangular 22 gauge GI tank having capacity of 90 litres. The highest temperature was observed between 2pm and 4pm.

Anonymous (1988) developed a natural circulation solar water heating system of 750 litre capacity. The solar collector was based on thermosyphon principle and could provide hot water at a temperature of 80-85^{0}C by the late afternoon. The overall efficiency of the system was 43 %.

Nayak, et. al. (1989) reported a concrete solar collector for providing domestic hot water. The collector was made up of thin concrete slabs with a network of PVC tubes of dia. 2 cm, embedded inside the concrete. A layer of GI wire mesh on either side provide necessary reinforcement to the concrete. The top of the slab was painted black and glazed. It was found that the collector with a pitch of 6cm gave the best performance at a flow rate of 0.02 litre/sec/m^2 of collector absorber area. The daily efficiency of the collector was about 37 %.

Kirian (1990) tested a low cost flat plate collector-cum-storage type solar water heater; at KCAET, Tavanur. The heater consisted of a concrete tank with dimensions of 150x70x10 cm and had a capacity of 100 litres. An absorber plate of size 150x70 cm was made of aluminium sheet of 22 gauge, painted black, was fixed in the tank. Glass cover was fixed at the top of the tank leaving an optimum air gap of 40 mm. This gave a peak temperature of 52^0C at 3pm, with an efficiency of 51%.

Garg, H.P. et. al. (1992) evaluated the performance of a closed loop hybrid air-to-water heater. A conventional solar air heater in conjunction with an air to water heat-exchanger of finned-shell-and-tube type, in which hot air from the collector transferred its heat to the cold water circulated from the storage tank during sunshine hours was considered for investigation. They concluded that at fixed mass flow rate of water, a higher mass flow rate of air resulted in higher storage tank temperature and vice versa. Storage volume also played an important role in determining the storage tank temperature. There was a fall in the storage tank temperature as the volume of the storage tank increased.

2.8.2 Work done Abroad

Kenna, (1983) conducted studies on multiple layer solar collector designed by Caouris, et al. Several transparent plates were placed above an absorber plate. The working fluid entered into the top and travelled down to the absorber through successive layers. Reduction in thermal losses could be achieved by multiple glazing, but resulted in increased optical losses. He concluded that the multiple layer collector was not a viable design.

Sokolov and Vaxmax (1983) developed a rectangular shaped and a triangular shaped integral compact solar water heaters. The system was a hybrid of flat plate collector and a water tank. Solar radiation was absorbed by a plate, which then transmitted its heat to the water in the channel adjacent to it. The capacity of the tank was 100 litres having $1m^2$ area and 10 cm depth. The advantages of the system are; better heat transfer from collector plate to fluid, since there are no pipes, no fins and no bonding resistance, and lower flow resistance.

Muneer (1985) had tested a built-in-storage solar water heater. It consisted of a rectangular box with the top face painted black and enclosed behind a single or double sheet of glass. The back surface and sides were insulated. He concluded that storage heater having 8 cm depth with double glazing was a good design.

Uhlemann and Bansal (1985) studied a pressurized and a non-pressurized thermosyphon systems. Both the systems essentially consisted of flat plate collectors, storage tanks and connecting pipes. The non-pressurized system had two collectors which were connected separately to the storage tank, both employing six evenly spaced parallel pipes. The pressurized system employed only one collector of meander type , which was connected to a storage tank. The measurement showed that for an incident solar energy of 6.75 kWh/m^2 of collector area, the useful energy available from the pressurized and non-pressurized systems was 3.06 kWh and 3.83 kWh per unit collector area respectively, yielding a daily average efficiency of 41% and 47%.

Vaxman and Sokolov (1985) designed an integral compact solar water heater. The casing of the system was made of 2.5 mm thick steel, and had a volume of 110 litres. The collector size was 190x100 cm and was painted black. The cover was of 3mm ordinary glass. A total of 24 iron-constant thermocouples were placed at various locations to indicate the temperature of an equal volume. The collector stood at a slope of 40^0 with the zenith facing south and had an initial uniform temperature of 27^0C.

Fanney and Klein (1987) had evaluated the performance of integral collector-storage solar water heater. Micro computer controlled data acquisition system was used to measure the total irradiance, effective black body temperature, ambient temperature, wind speed, internal tank temperature, and the temperature of the water entering and leaving each integral collector-storage unit.

Goetzherger and Rommel (1987) designed an integrated storage collector. The collector was a flat box whose front surface was the solar energy absorber. The advantages of the system were: the pure water to be heated could flow directly through it thus obviating the need for costly heat exchangers, no separate storage tank, no heat transfer circulation with pumps and controls, were necessary

Ecevit and Leslie (1979) conducted studies on triangular built-in-storage type solar water heater of various capacities. The solar water heater built consisted of triangular iron sectional storage volumes of 127, 168 and 220 litres. Three of each were built using 50 gauge GI sheet, 304 stainless steel, and 1mm thick copper. All nine collectors were contained in 1mm GI sheet box with 5 cm fibre glass at the back and sides. They concluded that the built-in-storage triangular collector showed a higher daily efficiency as a result of better heat transfer to the fluid.

Hamdan and Jubran (1992) experimented with a built-in-storage type solar water heater. The heater consisted of a rectangular 18 gauge GI tank and measuring 90x90x10 cm with an optimum volume of $0.081m^3$ and a collecting surface area of $0.81m^2$. The absorber plate was made of black painted galvanized steel plate. The heater was insulated at the bottom and sides using 5 cm sheet of mineral wool. The whole unit was installed with a tilt angle of 35^0 from the horizontal. They concluded that the efficiency of the built-in-storage type solar heater reach as high as 78% with a maximum water temperature of 70^0C and the cost was low compared to conventional flat plate collectors.

Siddiqui and Kimambo (1993) developed a compact integral solar water heater with an absorber plate area of $1m^2$ and a tank capacity of 75 litres. The depth of the channel between the absorber plate and the insulated partition varied from 5 mm to 15 mm. It was found that collector channel inlet and outlet temperatures, as well as the mean tank temperature increased in varying degrees with the increase in channel depth. The efficiency of the compact solar water heater also increased slightly with the increase in channel depth.

Hussain, et al. (1996) designed and developed two low cost built-in-storage type solar water heaters. The first one consisted of two plastic bowls, one inside the other with 5 cm thickness of insulation in between; crumpled newspaper balls were used as insulating materials. The diameter of the big one was 40 cm and that of small one was 38 cm; the area of small one was $0.12 m^2$ and had a capacity of 12 litres of water. The inside portion of the small vessel was painted black. A transparent plastic cover was tied around the smaller vessel. The temperature rise was 18^0C above the ambient temperature. The second one consisted of two earthen vessels in place of plastic bowls. The water temperature rise was 20^0C under the same conditions, above the ambient temperature.

Materials and Methods

MATERIALS AND METHODS

This chapter deals with the design details, selection criteria for components and test procedures of the collector-cum-storage type solar water heating system.

The functional requirements assumed for this solar water heating systems are as follows:

1. It should provide 30 litres of hot water around 65°C on a fine sunny day.
2. It should have optimum tilt to capture maximum solar radiation.
3. Cost of the solar water heating system should be low, so that it can be used by average villagers also.
4. The weight of the water heater should be such that it could be handled by one person.
5. The number of components should be kept minimum to facilitate easy maintenance, with good reliability and less initial cost.

3.1 The Collector area

On a clear sunny day, the solar water heating system is supposed to give 30 litres of hot water.

Capacity of collector = 30 litres

Heat gained for heating water = M x S x ΔT

Where, M – mass of water - 30 kg

S – specific heat - 1000 cal/kg ^{0}C

ΔT– temperature rise required, ^{0}C.

ΔT is taken as 30^{0}C, assuming that the minimum temperature of hot water required is 65^{0}C and the temperature of cold water is 35°C.

Heat gained for water heating = 30 x 1000 x 30 = 9,00,000 calories.

$= 9.0 \times 10^5 \times 4.187$ J = 1.047 kWh

(3.6×10^6 J = 1 kWh)

The solar energy that could be received by a flat natural surface varies from 5 kWh to 7 kWh/m^2 in most of the places in India.

Taking the solar energy available as 6 kWh/m^2 and the energy absorption efficiency of absorber plate as 60%.

The solar energy absorbed by the absorber plate = 6 x 0.6 = 3.6 kWh/m^2.

Average collector surface area = 1.047 / 3.6 = 0.2908 $m^2 \approx 0.3$ m^2.

The absorber area is also selected by the following method:

For a fixed absorber area, if the depth of storage tank increases, the water capacity also increases, and hence the storage water temperature decreases and vice versa. As the depth increases, the collector efficiency also increases, because the thermal losses to the outside air decreases. It can be seen that up to a depth of 10 cm the rise in efficiency is very fast, but above this, the rise in efficiency is negligible. (Garg, H.P. ,1975).

Since the capacity of the solar water heater is 30 litres and the depth of water in storage tank is 10 cm,

The collector surface area = 0.03 / 0.1 = 0.3 m^2.

3.2 Construction of the solar water heater

The various components of water heating system are discussed below with their materials of construction.

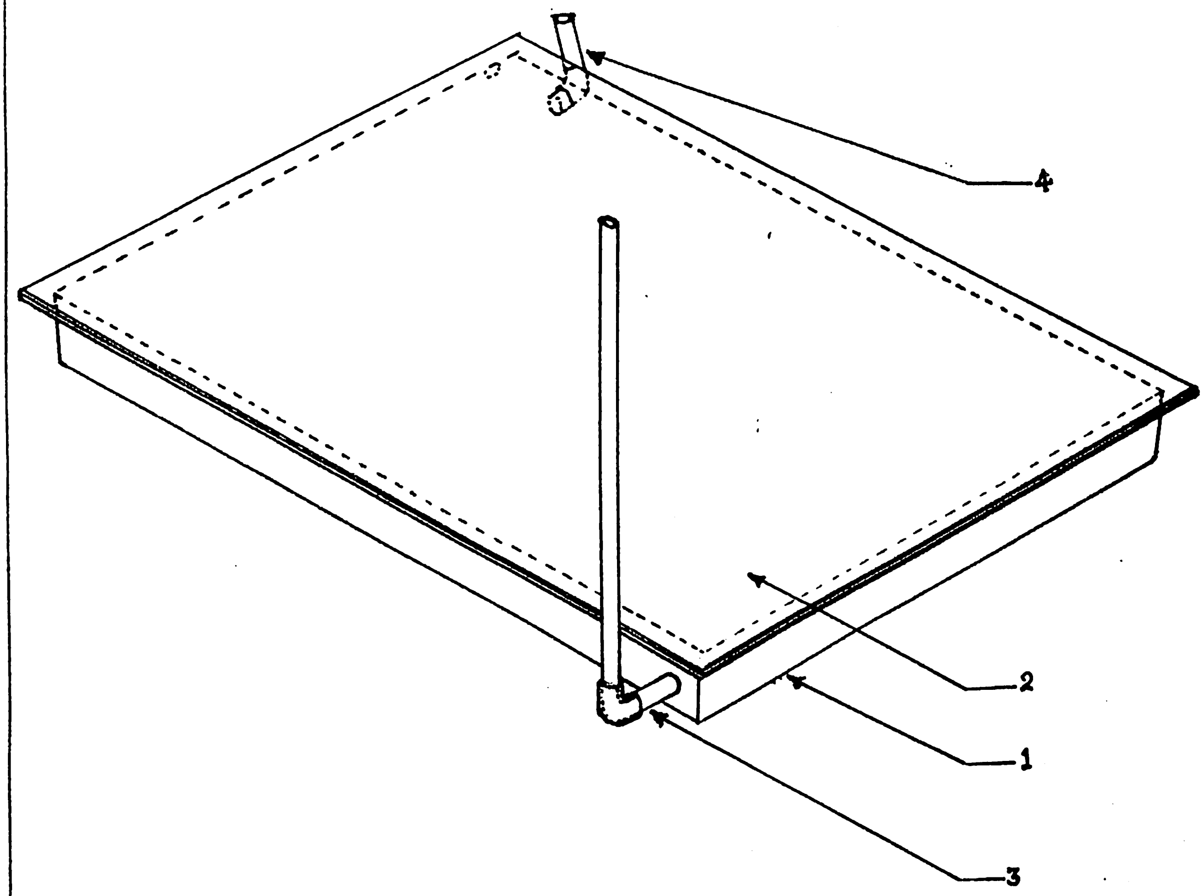
3.2.1 Cover plate

The cover plate over the absorber of the collector should have a high transmittance to the incoming solar radiation and opaque to the radiation emitted by the hot absorber. The transparent cover acts as a convection shield to reduce losses from the absorber plate beneath. The material most commonly used is glass for transparent covers. Glass has a higher transmittance factor than most other transparent materials, does not suffer from corrosion or ultraviolet instability; it has a considerable life, is reasonably cheap, and with care easily handled.

The specification of a typical good quality transparent glass solar collector cover would be: 4 mm (up to $1m^2$ collector); 5 mm (up to $2m^2$ collector); 6 mm (above $2m^2$ collector). Although two cover plates reduce the heat loss from the collector plate, each transparent cover reduces the radiation incident on the collector by about 10%. Therefore, single glazed collectors will outperform double glazed collectors at low and medium temperatures, and shows the highest thermal performance. So single plain glass plate of 4 mm thickness was used as the cover plate. Each water trough was covered using glass plate of 71 x 51 x 0.4 cm size.

3.2.2 Storage tank

The collector is enclosed in a container that holds the components together, protects them from weather. So many flat plate built-in-storage type solar water heaters have been developed already, but they were not yet popularized because of the high heat losses from the storage tank due to high thermal conductivity of the materials commonly used, like GI and MS. This defect is partially rectified by using insulation over the storage



1. Fibre glass trough
2. Glass cover
3. Inlet
4. Outlet

Fig. 6 ISOMETRIC VIEW OF THE SOLAR WATER HEATER tank, but this increased the total cost of the solar water heaters considerably, which limited the popularity again. These defects can partly be overcome by using a material having low thermal conductivity for the storage tank. Fibre glass is selected in this study as the material for storage tank, because of its low thermal conductivity (Appendix I), good mechanical resistance, light weight, low price, etc. Five rectangular troughs of 67 x 47 x 10 cm were made by using fibre glass of 3 mm thickness i.e. 3 layers of fibre glass joined by iso-thalak resin. The inner surface of the trough is polished smooth and the outer surface of the trough is coated with aluminium paint, which also reduces the heat losses from the trough. The trough is shown in Plate I. The four sides of the trough are slightly inclined outwards, in order to help the manufacturing process. A 2 cm projection is provided on the top of the fibre glass trough to fix the glass cover over it. The isometric view of the solar water heater is shown in Fig.6. The detailed dimensions of the storage trough are represented in Fig.8.

Inlet and outlet pipes are provided to carry cold water to and hot water from the collector. The inlet was provided on the longer side of the fibre glass trough at about 5 cm from the bottom edge. The outlet was provided on top corner, diagonally opposite to the inlet. Half inch PVC pipes were used for both inlet and outlet connections; it is also shown in Fig.6.

3.2.3 Collector assembly

Collector assembly is the most important component of the solar water heater as it receives the solar radiation and transmits the heat to the surrounding water. The collector of this water heater was fabricated out of 22 gauge aluminium sheet, because of its high

PLATE I. VIEW OF THE FIBRE GLASS TROUGH

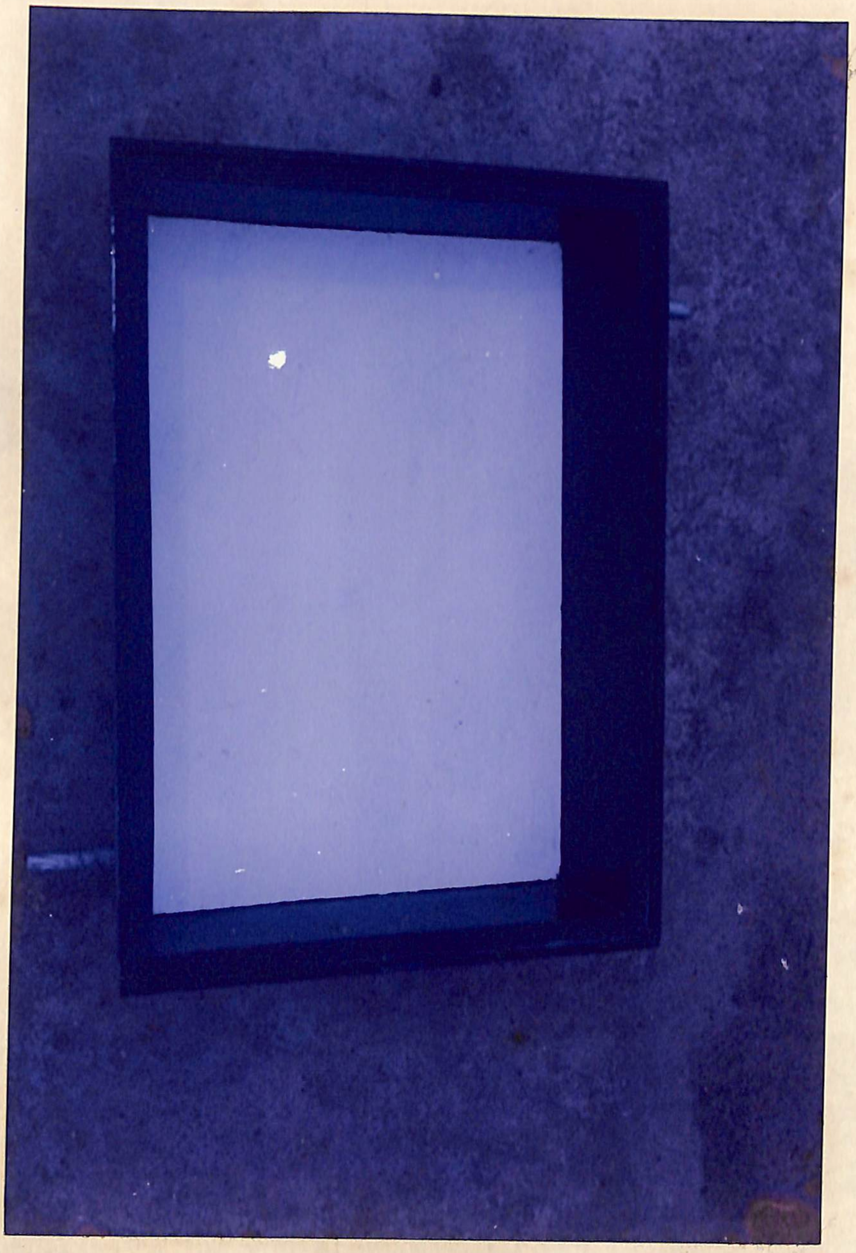
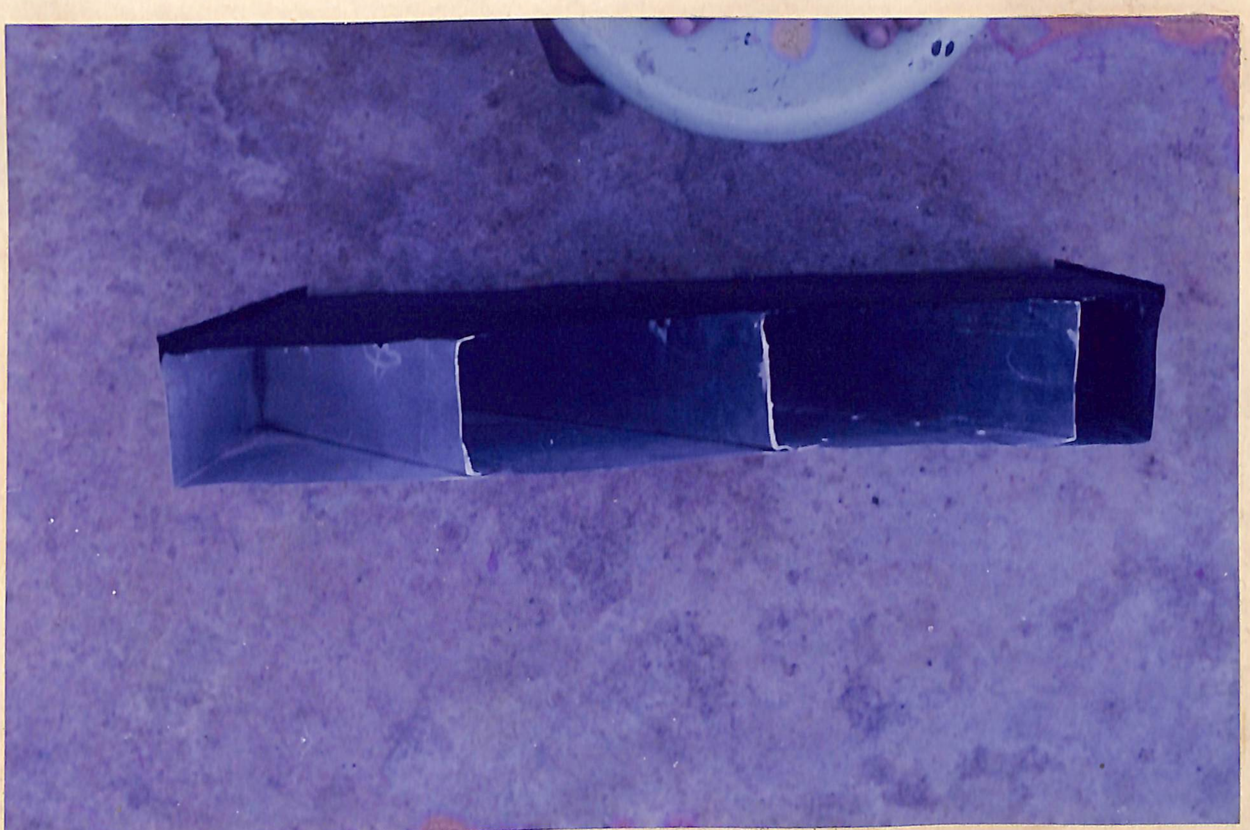


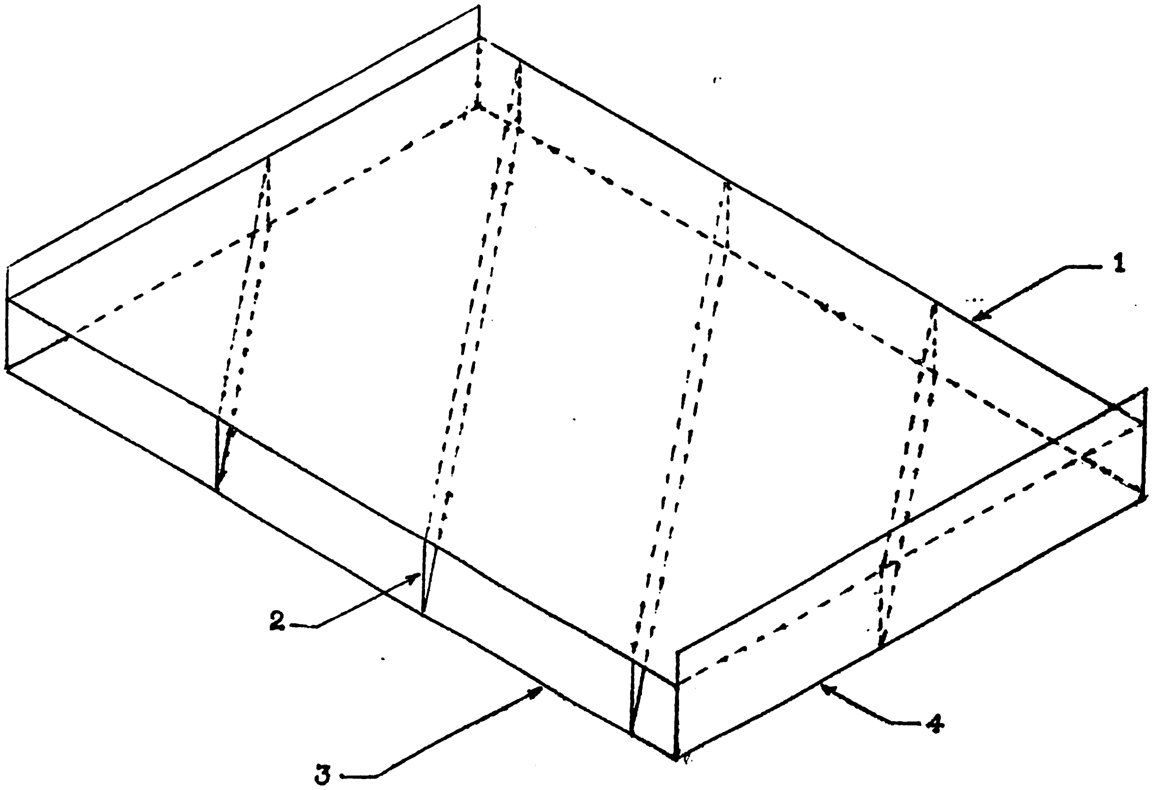
PLATE II. VIEW OF THE SUPPORTING ALUMINIUM SHEET ARRANGEMENT



thermal conductivity, lower cost compared to copper, lighter weight and less corrosion. It had an absorber plate at the top and a similar parallel plate at the bottom, both being interconnected at the ends by two vertical sheets and in between the area by four vertical spacers. These parallel spacers were fixed at an angle of 40^0 to the horizontal ends. The two vertical sheets at the ends were made by bending the edges of the bottom sheets upwards. The collector assembly had an overall size of 65 x 45 x 9 cm height. The top absorber plate was blackened using Epilux 4 enamel black board paint, which absorbs the solar radiation and get heated up. Thus the water nearby the absorber plate also get heated up. As this hot water rises up due to its reduction in density, the water at the lower layers will not get heat. The bottom parallel plate connected to the absorber plate through aluminium spacers over comes this draw back and transmits heat to almost all parts inside the trough heating the water more uniformly.

The arrangement of the collector assembly is shown in Fig 7 & in Fig 8, and in Plate II & III. It was assumed that the blackened absorber surface had an absorptivity of 0.96.

In this study the position of the absorber plate from the glass cover was optimized by constructing five solar water heaters with different absorber plate positions (Plate III). The position of the absorber plate with respect to the top glass cover was kept at different values by changing the width of the spacers that connect to the bottom parallel plate. The different configurations of the solar water heater and their constructional features are explained below. The five different versions are, designated suffixing the depth in cm of the absorber plate from the top glass cover plate,



1. Absorber plate
2. Aluminium spacers
3. Bottom Aluminium plate
4. Side aluminium sheet

Fig. 7 ISOMETRIC VIEW OF ALUMINIUM SHEET ARRANGEMENT

i) **Solar water heater I ($SWH_{1.0}$)**

In this solar water heater the absorber plate was placed at a depth of 1 cm from the glass cover. The height of the absorber plate from the bottom of the tank was 9 cm. The width of the spacers i.e. the gap between the absorber plate and the bottom plate was 8 cm. The arrangement of the collector inside the storage tank is shown in Fig.8.

ii) **Solar water heater II ($SWH_{3.0}$)**

The absorber plate was placed at a depth of 3 cm from the glass cover. The width of the spacers was 6 cm. The absorber plate was at a height of 7 cm from the bottom of the storage tank. The gap between the absorber plate and the bottom aluminium plate was 6 cm. Fig.9 shows the arrangement of the whole setup. Other constructional features and fixation of the absorber in the storage tank are same as explained earlier.

iii) **Solar water heater III ($SWH_{5.0}$)**

In this version of solar water heater the absorber plate was positioned at a depth of 5 cm from the top glass cover. The width of the spacers i.e. the gap between the absorber plate and bottom parallel plate was 4 cm. The absorber plate was placed at a height of 5 cm from the bottom of the storage tank. The arrangement is shown in Fig.10.

iv) **Solar water heater IV ($SWH_{7.0}$)**

Solar water heater IV is shown in Fig 11. In this solar water heater the absorber plate was placed at a depth of 7 cm from the glass cover. The gap between the absorber plate and the bottom parallel plate, i.e. the width of the spacers was 2 cm. The absorber

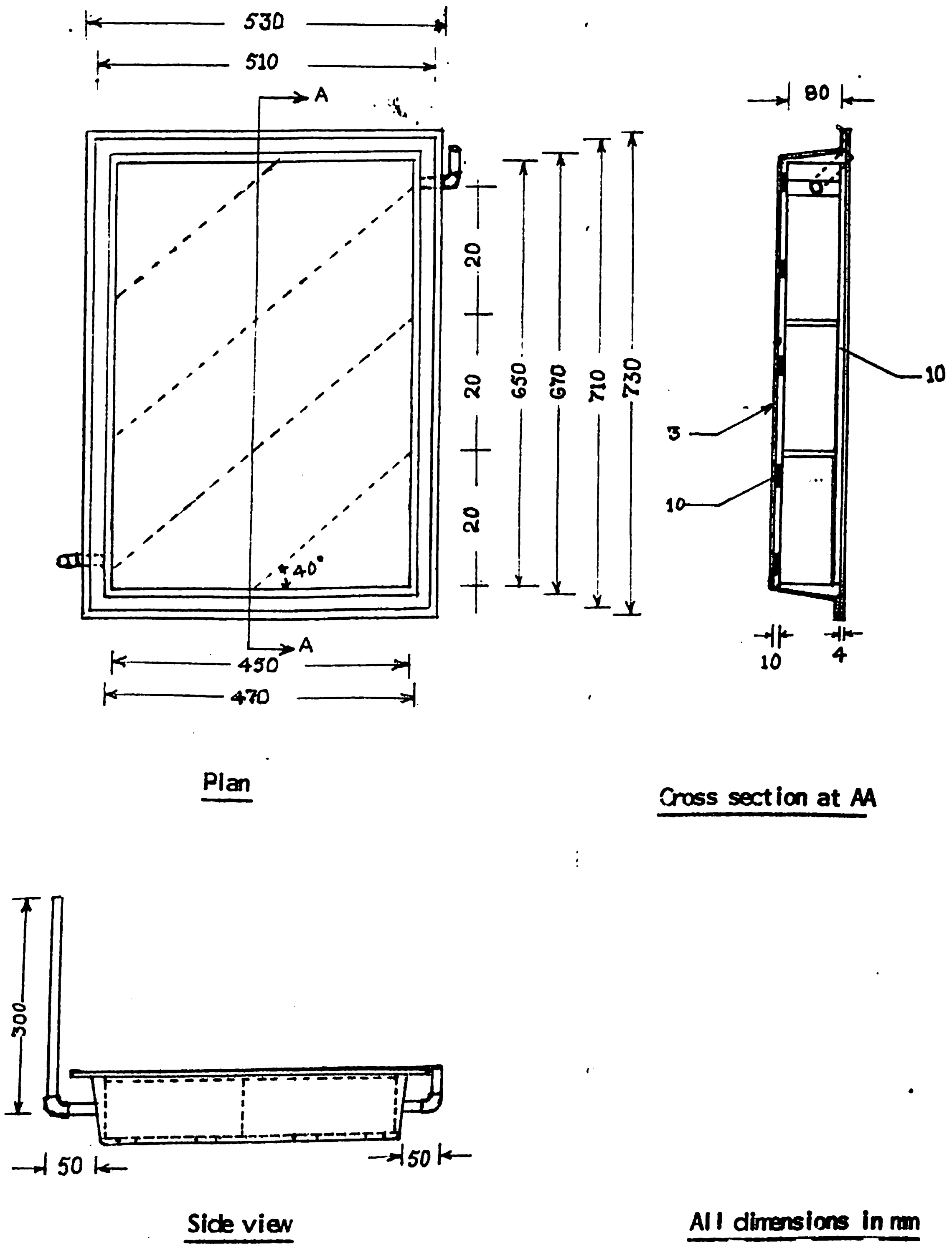


Fig. 8 SCHEMATIC DIAGRAM OF SOLAR WATER HEATER I

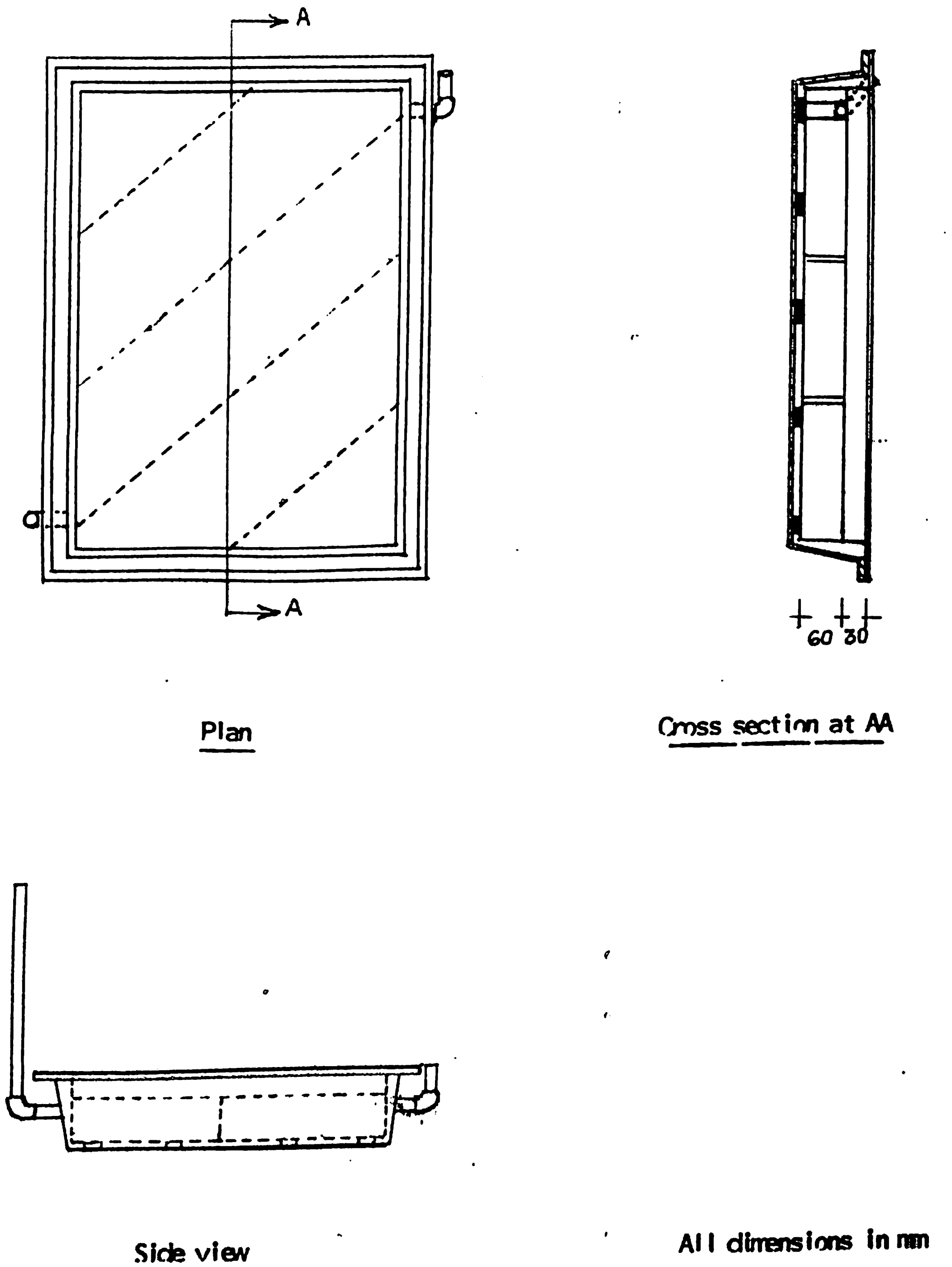
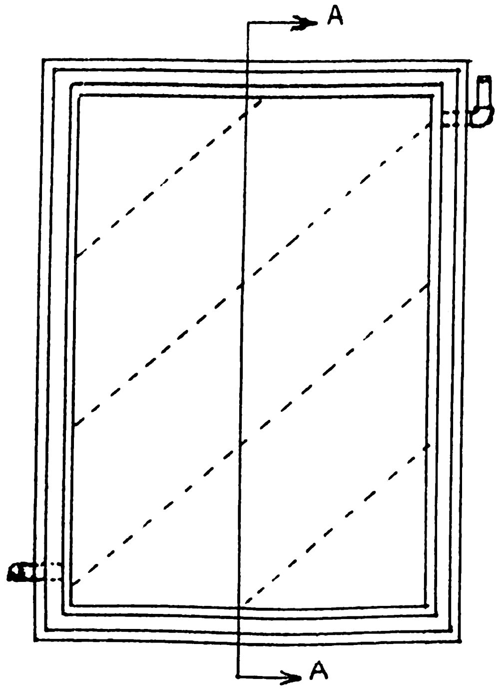
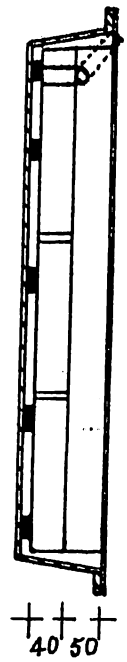


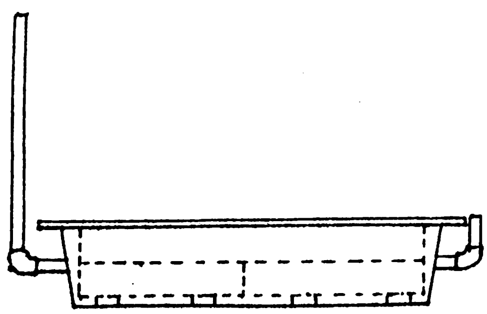
Fig. 9 SCHEMATIC DIAGRAM OF SOLAR WATER HEATER II



Plan



Cross section at AA



Side view

All dimensions in mm

Fig. 10 SCHEMATIC DIAGRAM OF SOLAR WATER HEATER III plate was positioned at a height of 3 cm from the bottom of the storage tank. The other constructional features and fixations are same as that explained earlier.

iv) Solar water heater V ($SWH_{9.0}$)

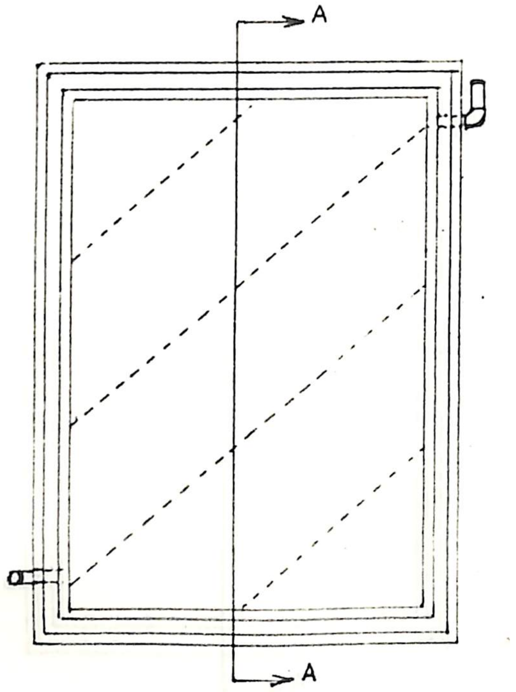
In this solar water heater, a single aluminium sheet of 83 cm x 45 cm was used. Two sides of the sheet were bent vertically upward with 9 cm in width each in the transverse sides. The top surface of the aluminium sheet and the faces of the side plates facing each other were painted black. The absorber was placed in the fibre glass trough as shown in Fig.12. The depth of the absorber plate from the top glass cover was 9 cm. The height of the absorber plate was 1 cm from the bottom of the fibre glass trough. The absorber plate was positioned in such a way that 1 cm gap was provided in all sides from the fibre glass trough.

3.3 Fabrication of the solar water heaters

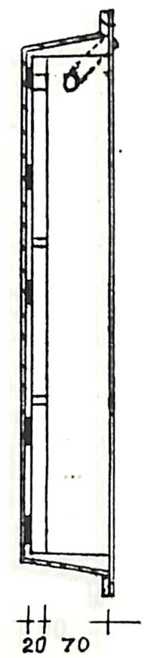
The built-in-storage type solar water heaters were made according to the design details in section 3.1. Five collector assemblies were fabricated as per the design discussed in section 3.2.3 and is shown in Plate III. The fibre glass troughs were made by a firm, namely M/s glass fibre industries, Thrissur as per the dimensions and details given to them. The collector absorbers were fixed inside the fibre glass trough and the top of the troughs were covered using plain glass plate of 4 mm thick.

3.4 Installation of the solar water heaters

This study was undertaken at KAU, KCAET, Tavanur in Malappuram District. Tavanur is situated at $10^0 52'30''$ North latitude and 76^0 East longitude. The site was



Plan



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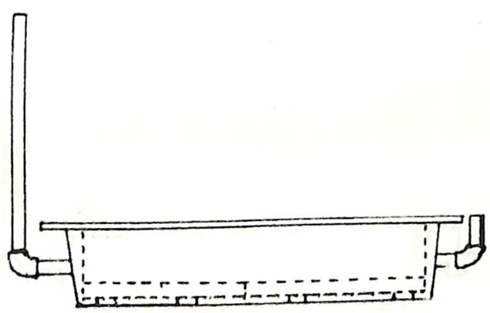
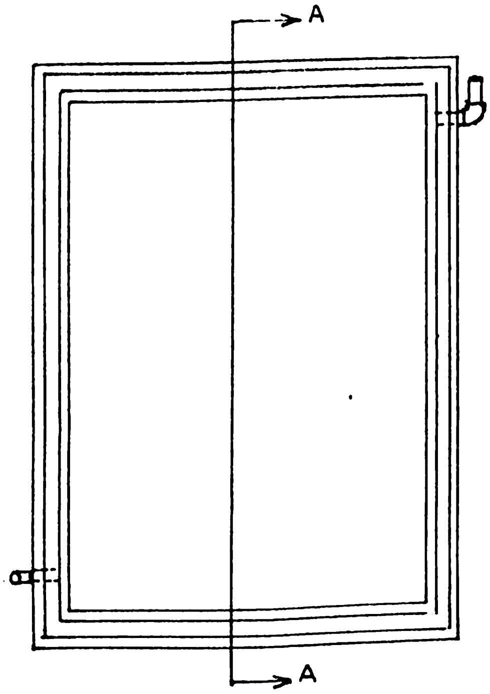
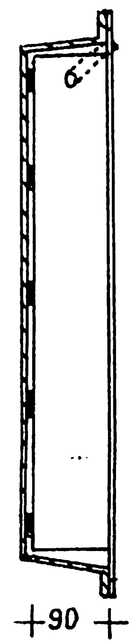


Side view

All dimensions in mm

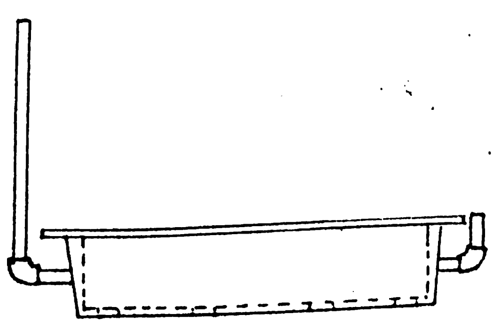
Fig. 11 SCHEMATIC DIAGRAM OF SOLAR WATER HEATER IV





Plan

Cross section at AA



Side view

All dimensions in mm

Fig. 12 SCHEMATIC DIAGRAM OF SOLAR WATER HEATER V carefully selected, obstructions such as buildings, trees etc. that may cause shade were avoided. The solar water heaters were installed at the top of one of the buildings in the college campus.

3.5 Orientation of the solar water heaters

To obtain maximum solar radiation and to minimize optical losses due to reflection from the absorbing surface, it is essential that the incident radiation strike the absorber surface at right angles. The angle of incidence of solar radiation on the earth surface depends upon the parameters like latitude of the place, time of the day, and time of the year.

The optimum roof angle for solar water heater is approximated by the degree of latitude. Since the atmospheric temperature is more during the summer months, The inclination is kept at latitude minus 15^0. For maximum utilization in the winter months the inclination is kept at 15^0 more than the latitude of the place. For year round utilization the inclination is kept at the latitude of the place. In Kerala, since the temperature remains more or less same during winter and summer, the heaters were given an inclination of $10^0 52' 30''$ from the horizontal facing due South to collect maximum solar radiation. Plate IV shows the solar water heaters after installation.

3.6 Performance of the solar water heaters

The solar water heaters were exposed to solar radiation directly under open space. The performance evaluations were conducted during the day time from 8am to 5pm. In the early morning hours the incident solar radiation was not enough to bring the heaters to

PLATE III. VIEW OF FIVE COLLECTOR ABSORBERS

PLATE IV. PLACEMENT OF THE SOLAR WATER HEATERS IN THE ROOF TERRACE

the operating condition. Once the heater started giving useful energy, the following observations were taken and recorded at every 1hour interval

1. Inlet water temperature (Ti) 2. Outlet water temperature (To)

3. Ambient temperature (Ta) 4. Solar flux incident on the collector plane

The performance was evaluated by adopting two different methods; namely,

i) hourly reading method

ii) hourly filling method

In the hourly reading method the solar water heaters were filled daily at 8am with fresh water. From then onwards the above said readings were recorded at every 1hour interval.

In the second method, i.e. in the hourly filling method, the solar water heaters were filled during every 1hour interval with fresh water from 8am to 5pm. In this method also the said readings were taken at every 1h interval.

The water temperatures were noted with a mercury-in-glass thermometer (Appendix II), and is shown in Plate V.

3.6.1 Measurement of the intensity of solar radiation

Total solar radiation received on horizontal surface was measured by using solar intensity meter i.e.'Suryamapi'. The meter is calibrated for both mW/cm^2 and langleys/h . Suryamapi is a hand-held portable solar intensity meter used for the measurement of total global (direct plus diffuse) solar radiation.

PLATE V. MEASUREMENT OF OUTLET TEMPERATURE OF SOLAR WATER HEATERS USING THERMOMETERS

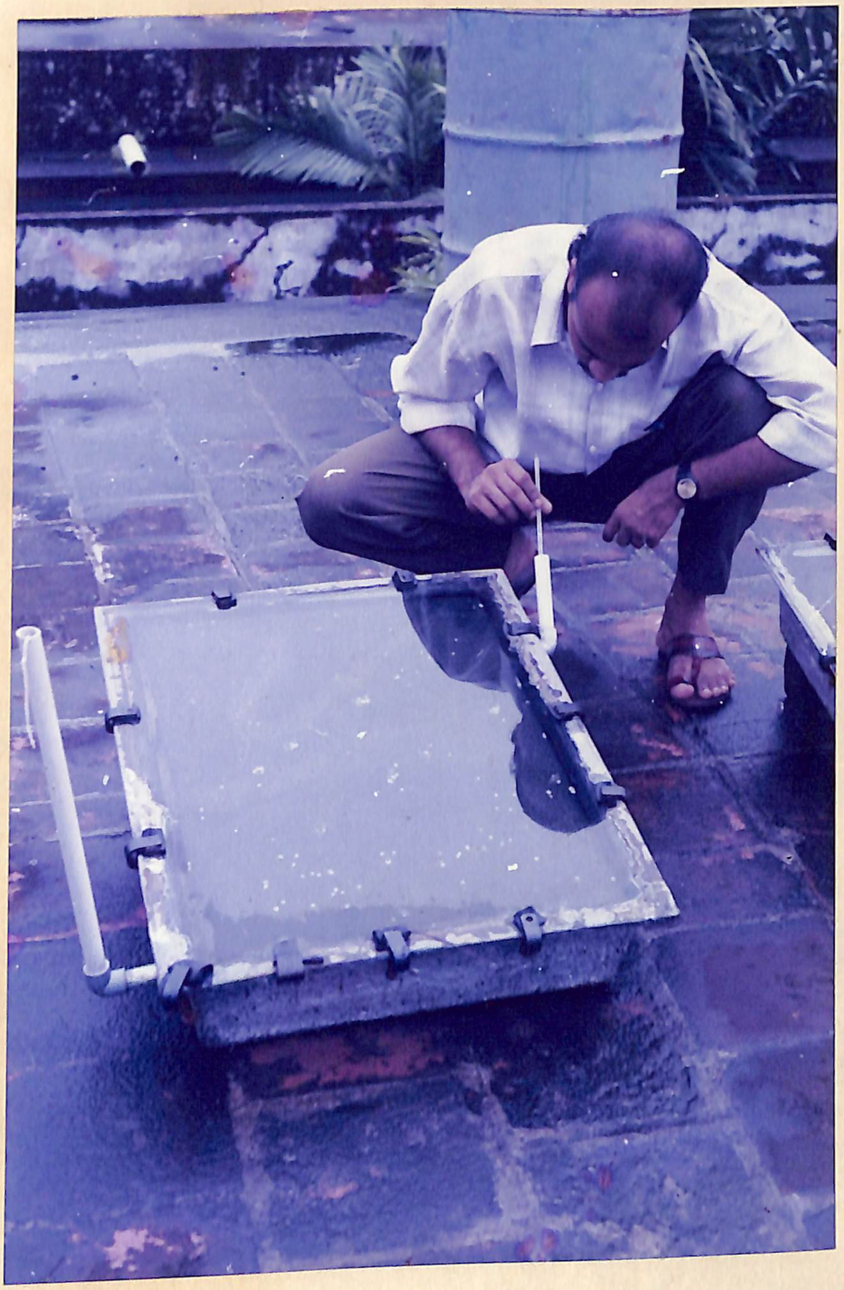
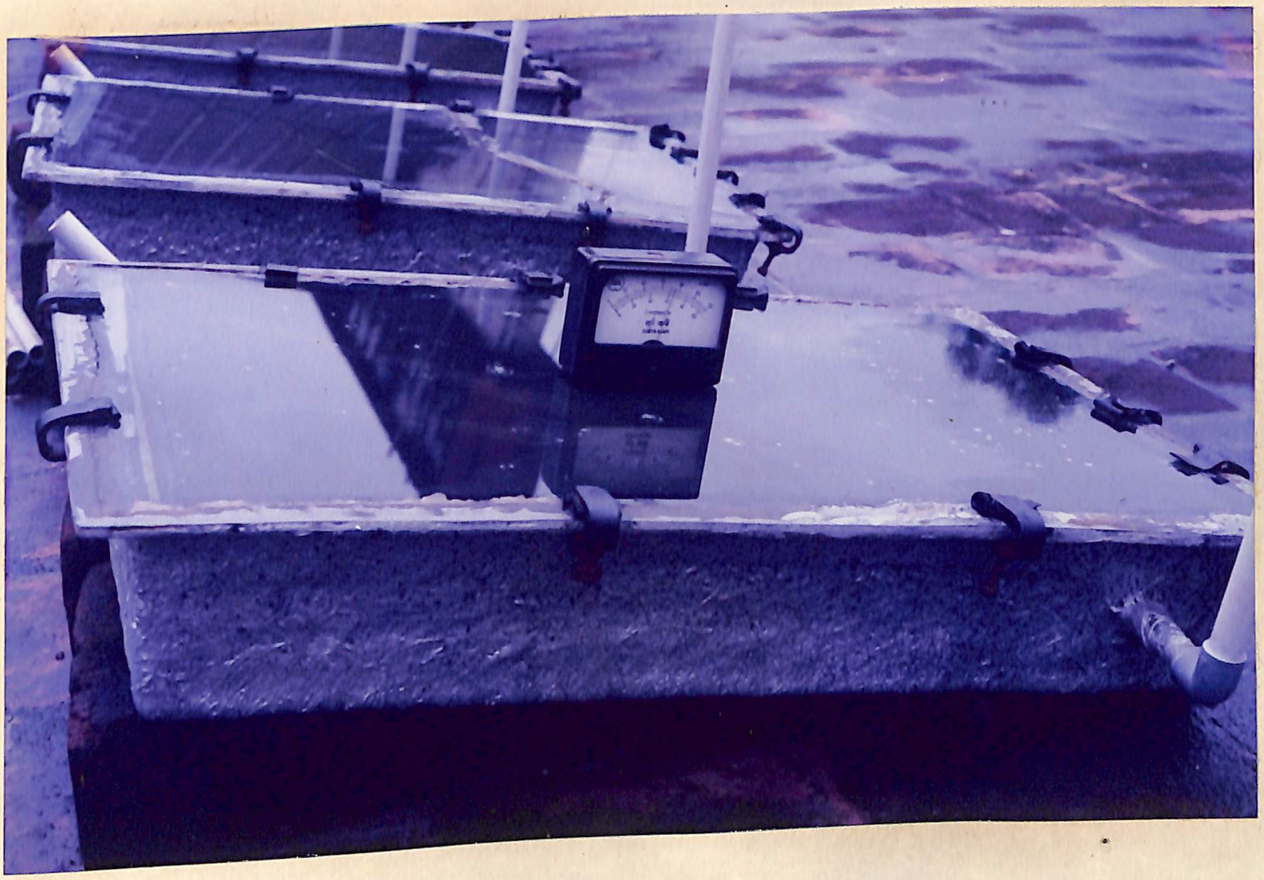


PLATE VI. MEASUREMENT OF SOLAR RADIATION USING SOLAR INTENSITY METER



The sensing solar cell, a specially fabricated silicon cell, mounted at the top of the meter, is connected through a suitable circuitry to an ammeter meter. The response of the sensing element is linear over a wide range of intensities. For measuring the intensity of incident radiation on an inclined surface, the plane of the sensing solar cell should be kept parallel to the surface as shown in Plate VI. The specification of the suryamapi is given in Appendix II.

3..6.2 Heat Balance Equation

The useful heat delivered by a solar collector = Heat absorbed by the solar collector - Heat lost to the surroundings

$$Q = A\,[(H_T - U_L\,(T_A - Ta)]$$

$$\text{But, } Q = Ww\,(dTw/dt) + Wa\,(dT_A / dt)$$

$$\text{i.e., } Ww\,(dTw/dt) + Wa\,(dT_A / dt) = A\,[(H_T - U_L\,(T_A - Ta)]$$

At ideal conditions, $Tw = T_A$

$$(dTw/dt) = (dT_A / dt)$$

$$(Ww + Wa)\,dTw = [(H_T A - U_L A(T_A - Ta)]\,dt$$

$$N\,dTw = [(H_T A - U_L A(T_A - Ta)]\,dt$$

$$\text{On integrating, } Tw = Two + P\,(t - to)/N$$

Using this equation, the temperature of water inside the solar water heaters can be predicted, at any time of the day

Where, A – absorber area, m^2

H_T – total solar radiation falling on the absorbing surface, $kcal/m^2/h$

Wa – water equivalent of collector-cum-storage tank, kg

Ww – weight of water in the storage tank, kg dtw – rate of rise of average water temperature, ^{0}C

Ta – ambient temperature, ^{0}C

Tw – temperature of hot water, ^{0}C

T_A – absorber surface temperature, ^{0}C

U_L – heat transfer coefficient

$P = H_T A - U_L (Ta-TA)$

$N = Ww + Wa$

t - time

dT_A / dt – rate of rise of average temperature, ^{0}C

3.6.3 Efficiency of the solar water heater

Collection efficiency is the measure of collector performance. It is defined as the ratio of the useful heat gain over any time period to the incident solar energy over the same time period

Efficiency, η = Useful heat gained / radiation incident on the collector

$= M \times S \times (To-Ti) / H_s \times A$

Where, M – mass of water heated up (kg)

S – specific heat of water (J/kg^{0}C)

To – outlet temperature of hot water (^{0}C)

Ti – initial temperature of cold water (^{0}C)

H_s -- solar radiation on unit area on horizontal surface of earth (W/m^2)

A – absorbing surface area of the water heating system (m^2)

Results and Discussion

RESULTS AND DISCUSSION

The results of the performance evaluation of the built-in-storage type solar water heaters are discussed in this chapter.

4.1 Performance Results

The performance evaluation was conducted from 21st April '98 to 4th May 1998. The solar water heaters were placed at the latitude of Tavanur, namely 10^0 52' 30''. These water heaters were tested under two different test conditions. In the first one, water heaters were filled with water at 8am, then the outlet and ambient temperatures, and solar radiation were recorded for every 1 h interval during 8am to 5pm from 21st April '98 to 27th April 1998. Under the second test condition, solar water heaters were filled with water at every 1 h interval during 8am and 5pm from 28th April '98 to 4th May 1998; and the same set of readings were recorded. The outlet temperatures were noted from two points, i.e. one on the top and the other from the bottom in the outlet portion, and the average of these two was taken for calculations; to minimize the error that might occur due to the position of the absorber plate.

Table 1 shows the solar radiation received during the period of study at Tavanur. A maximum solar intensity of 980 W/m^2 was noted on two days at 12 noon. It is clear from the table that the variation of daily average solar radiation received during the experiment was very minimum.

Table 1. Solar radiation received at Tavanur

Date	Solar radiation (W/m²)										Average solar radiation (W/m²)
	8am	9am	10am	11am	12noon	1pm	2pm	3pm	4pm	5pm	
21-04-'98	210	270	420	800	900	810	670	520	380	160	514
22-04-'98	50	380	400	880	920	880	760	580	400	160	541
23-04-'98	210	400	650	820	880	820	750	560	400	140	563
24-04-'98	200	370	420	780	900	870	820	640	430	180	561
25-04-'98	190	250	400	820	910	850	780	590	310	190	529
26-04-'98	70	310	440	810	920	780	650	490	360	180	501
27-04-'98	60	370	450	870	930	880	750	570	410	170	546
28-04-'98	40	480	700	880	960	850	740	550	390	150	574
29-04-'98	70	480	690	870	950	900	760	590	370	170	585
30-04-'98	80	480	680	850	920	880	780	600	360	160	579
01-05-'98	50	500	690	890	980	840	760	560	380	160	581
02-05-'98	70	470	690	880	950	850	750	580	360	170	577
03-05-'98	70	480	700	900	960	850	740	570	390	180	584
04-05-'98	70	490	700	910	980	820	750	570	390	180	586

4.1.1 Solar water heaters evaluated under the first test condition

The performance of the solar water heaters under the first test condition are discussed below:

Performance of solar water heater I ($SWH_{1.0}$)

The solar water heaters were tested from 21st to 27th April, 1998 under the first test condition. Table 2 shows the average solar radiation, average ambient temperature, inlet temperature, average outlet temperature at 3pm, and daily efficiency of the solar water heater during the experiment period. A maximum heater efficiency of 54.56% was observed on 26-04-'98. The maximum average outlet temperature of 58.5^{0}C was observed on 24-04-'98 at 3pm. The performance of the solar water heaters on 24-04-'98, are presented in Appendix III. The hourly variations of the outlet and ambient temperatures, and solar intensity are shown in Fig.13. It is evident from the figure that the solar intensity reached a maximum at 12 noon. The maximum outlet temperature of 64^{0}C was observed at 3pm on 24th and 25th of April 1998. The variation in the ambient temperature was less.

Performance of solar water heater II ($SWH_{3.0}$)

It is clear from the table 3 that the maximum average outlet temperature was observed on 24-04-'98 and it was 60^{0}C. The efficiency of the solar water heater reached a maximum value of 55.72% on 26-04-'98. Fig. 14 shows the performance of the solar

Table 2. Daily average solar radiation, inlet, outlet and ambient temperatures, and efficiency of solar heater I ($SWH_{1.0}$) under the first test condition from 8 to 17 hours

Date	Average solar radiation (W/m^2)	Average ambient temperature (^{0}C)	Inlet temperature (^{0}C)	Outlet temperature (^{0}C)	Efficiency (%)
21-04-'98	514	34.45	34	56.0	49.78
22-04-'98	541	34.58	33	57.0	51.80
23-04-'98	563	34.89	33	57.5	50.61
24-04-'98	561	33.70	34	58.5	50.79
25-04-'98	529	34.13	34	58.0	52.77
26-04-'98	501	34.35	34	57.5	54.56
27-04-'98	546	34.15	33	57.5	52.19

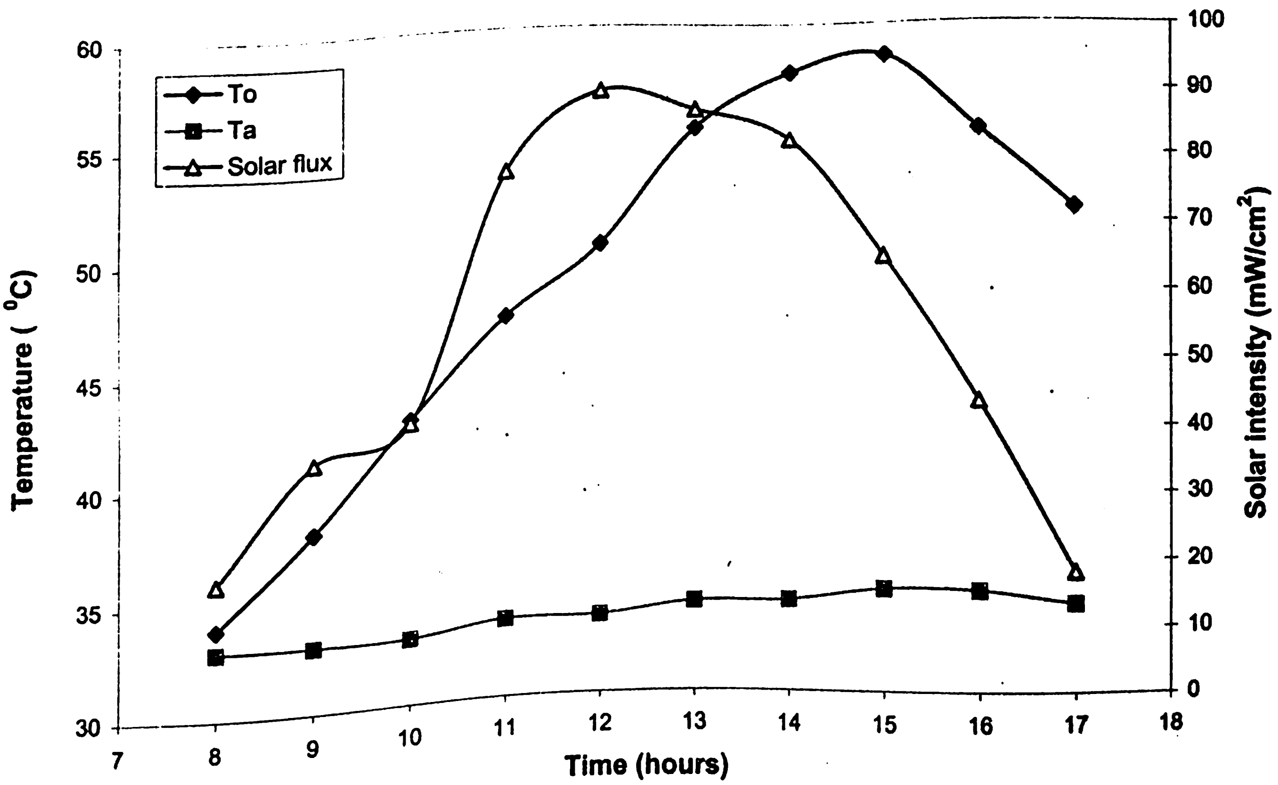


Fig. 13. Performance of solar water heater I ($SWH_{1.0}$) on 24-04-'98

Table 3. Daily average solar radiation, inlet, outlet and ambient temperatures, and efficiency of solar heater II ($SWH_{3.0}$) under the first test condition from 8 to 17 hours

Date	Average solar radiation (W/m^2)	Average ambient temperature (^0C)	Inlet temperature (^0C)	Outlet temperature (^0C)	Efficiency (%)
21-04-'98	514	34.45	34	57.0	52.04
22-04-'98	541	34.58	33	58.5	54.82
23-04-'98	563	34.89	33	58.0	51.65
24-04-'98	561	33.70	34	60.0	53.90
25-04-'98	529	34.13	34	59.0	54.97
26-04-'98	501	34.35	34	58.0	55.72
27-04-'98	546	34.15	33	58.5	54.32

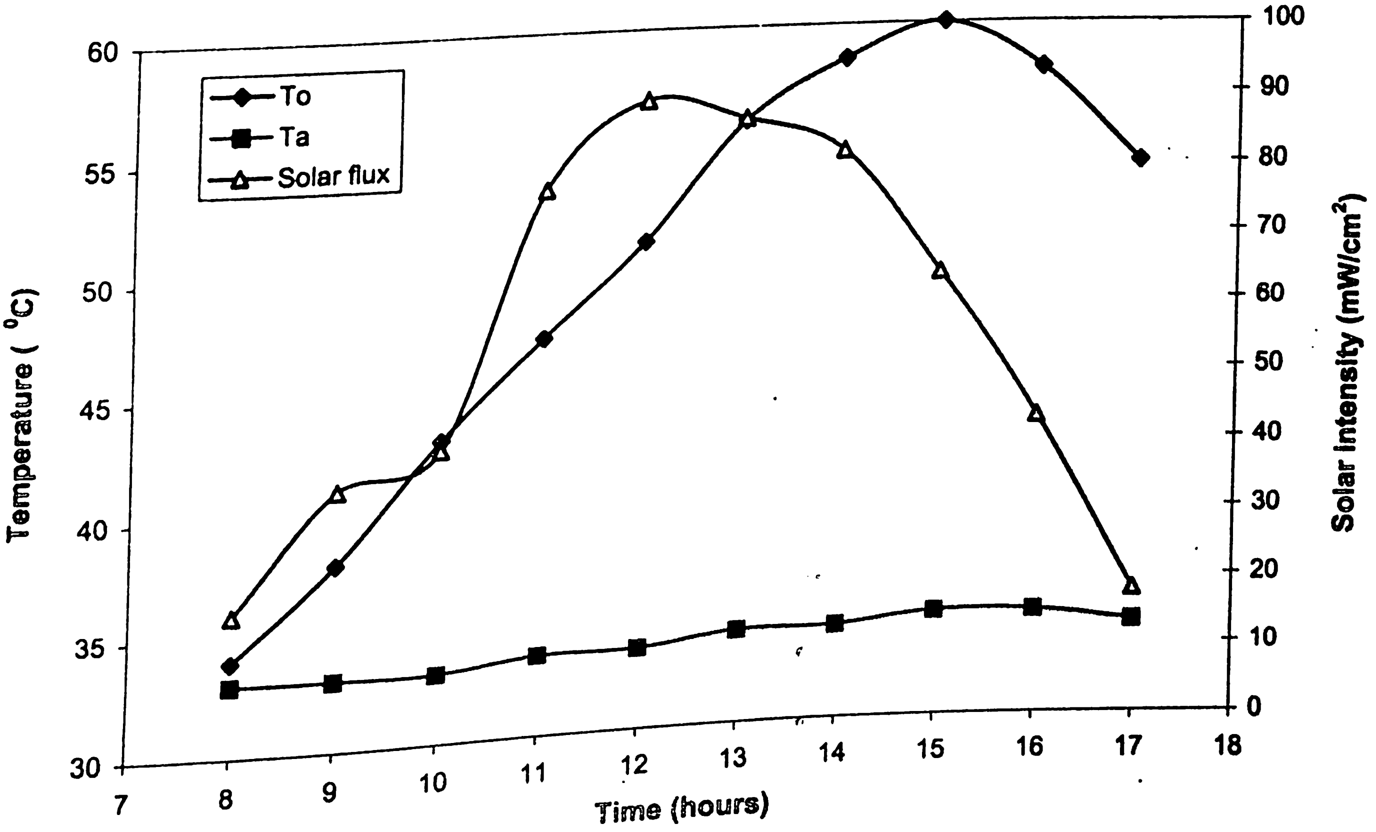


Fig. 14. Performance of solar water heater II ($SWH_{3.0}$) on 24-04-'98

water heater on a clear sunny day during the experiment. It is observed that the maximum outlet temperature was 61^{0}C at 3pm on 24-04-'98.

Performance of solar water heater III ($SWH_{5.0}$)

Table 4 shows the performance of this solar water heater during the experiment. The maximum efficiency of 48.75% was obtained on 26-04-'98, and the maximum outlet temperature of 56^{0}C was observed on 25-04-98 at 3pm as evident from the Table 4. The performance of the solar water heater on a clear sunny day is shown in Fig.15. An average outlet temperature of 55.5^{0}C was observed with the solar intensity of 640 W/m^2 at 3pm on 24-04-'98. The maximum outlet temperature of 58^{0}C was observed at 3pm on 25-04-'98

Performance of solar water heater IV ($SWH_{7.0}$)

Performance details of this solar water heater is presented in Table 5. It is obvious from the table that the maximum efficiency attained by the solar water heater was 48.75% on 26-04-'98 and the maximum average outlet temperature noted was 55.5^{0}C on 25-04-'98. Observations of the solar water heater from 8am to 5pm on a clear sunny day is given in Appendix III; it is also represented in Fig.16. The variation in outlet temperature is clear from this figure, along with the corresponding solar intensity and ambient temperature. The maximum outlet temperature of 57^{0}C was observed at 3pm on 25th and 26th April '98.

Table 4. Daily average solar radiation, inlet, outlet and ambient temperatures, and efficiency of solar heater III ($SWH_{5.0}$) under the first test condition from 8 to 17 hours

Date	Average solar radiation (W/m^2)	Average ambient temperature (^0C)	Inlet temperature (^0C)	Outlet temperature (^0C)	Efficiency (%)
21-04-'98	514	34.45	34	53.5	44.12
22-04-'98	541	34.58	33	54.5	45.15
23-04-'98	563	34.89	33	55.0	45.57
24-04-'98	561	33.70	34	55.5	44.57
25-04-'98	529	34.13	34	56.0	48.37
26-04-'98	501	34.35	34	55.0	48.75
27-04-'98	546	34.15	33	55.5	47.93

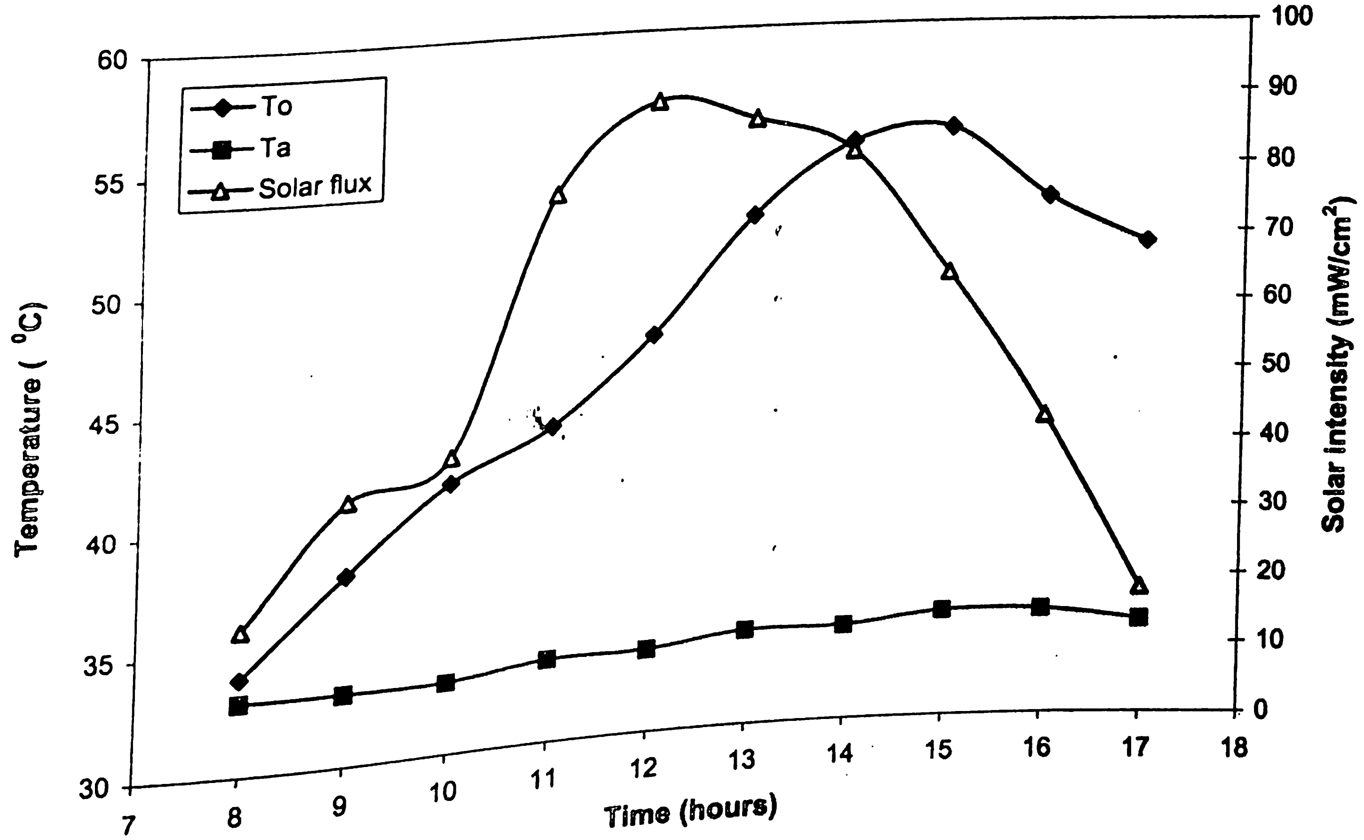


Fig.15. Performance of solar water heater III ($SWH_{5.0}$) on 24-04-'98

Table 5. Daily average solar radiation, inlet, outlet and ambient temperatures, and efficiency of solar heater IV ($SWH_{7.0}$) under the first test condition from 8 to 17 hours

Date	Average solar radiation (W/m^2)	Average ambient temperature (^0C)	Inlet temperature (^0C)	Outlet temperature (^0C)	Efficiency (%)
21-04-'98	514	34.45	34	53.0	42.99
22-04-'98	541	34.58	33	53.5	44.07
23-04-'98	563	34.89	33	54.5	44.42
24-04-'98	561	33.70	34	54.5	42.50
25-04-'98	529	34.13	34	55.5	47.27
26-04-'98	501	34.35	34	55.0	48.75
27-04-'98	546	34.15	33	55.0	46.86

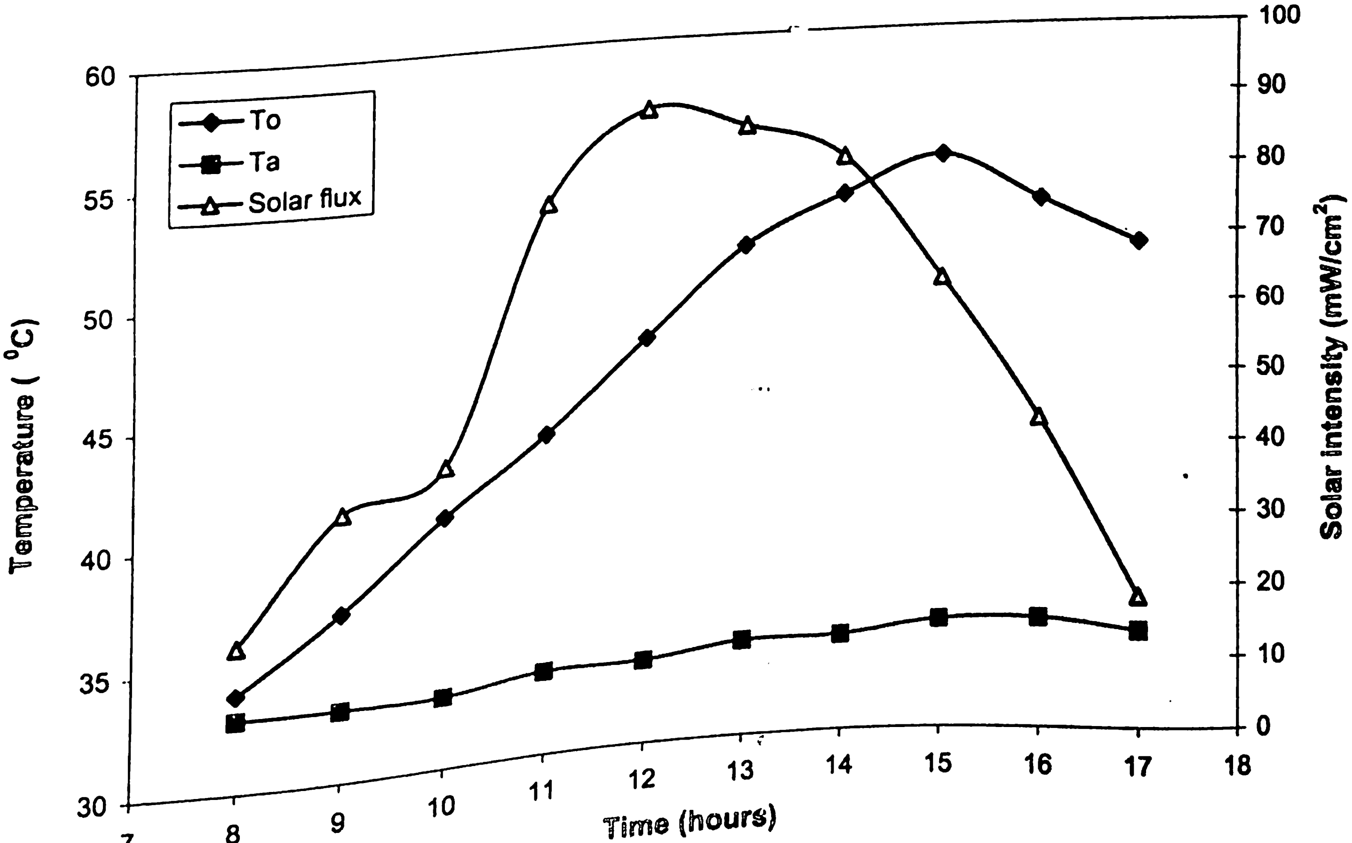


Fig.16. Performance of solar water heater IV ($SWH_{7.0}$) on 24-04-'98

Performance of solar water heater V ($SWH_{9.0}$)

The daily performance of the solar water heater during the experiment period is shown in Table 6. It is clear from the table that the maximum efficiency of 47.59% was observed on 26-04-'98 and a maximum average outlet temperature of 55.5^{0}C on 25-04-'98 at 3pm. The hourly performance of the solar water heater on a clear sunny day during the experiment is shown in Fig.17. The maximum outlet temperature of 56^{0}C was observed on 25-04-'98 at 3pm.

4.1.1.1 Comparative evaluation of the performance of the solar water heaters under the first test condition

The daily efficiencies of the solar water heaters during the period of experiment are shown in Fig.18. It is clear from the figure that the efficiency of $SWH_{3.0}$ is always higher than the efficiencies of other solar water heaters. The hourly outlet temperature of $SWH_{3.0}$ is higher than that of the other solar water heaters, as shown in Fig.19. The efficiency of $SWH_{1.0}$ is comparatively higher than $SWH_{5.0}$, $SWH_{7.0}$ and $SWH_{9.0}$. Even though the efficiency of $SWH_{5.0}$ is slightly higher than the efficiencies of $SWH_{7.0}$ and $SWH_{9.0}$, the variation is low.

It is clear from the above comparison that $SWH_{3.0}$ having a gap of 3cm between the top glass cover and the absorber plate, outperforms other heaters; this might be because of the good thermal energy transfer to the water and low heat loss from the system. The performance of $SWH_{1.0}$ might have been affected by enhanced thermal losses through convection, because the gap between the top glass cover and bottom

Table 6. Daily average solar radiation, inlet, outlet and ambient temperatures, and efficiency of solar heater V ($SWH_{9.0}$) under the first test condition from 8 to 17 hours

Date	Average solar radiation (W/m^2)	Average ambient temperature (^0C)	Inlet temperature (^0C)	Outlet temperature (^0C)	Efficiency (%)
21-04-'98	514	34.45	34	53.0	42.99
22-04-'98	541	34.58	33	54.0	45.15
23-04-'98	563	34.89	33	54.5	44.42
24-04-'98	561	33.70	34	54.5	42.50
25-04-'98	529	34.13	34	55.5	47.27
26-04-'98	501	34.35	34	54.5	47.59
27-04-'98	546	34.15	33	54.5	45.80

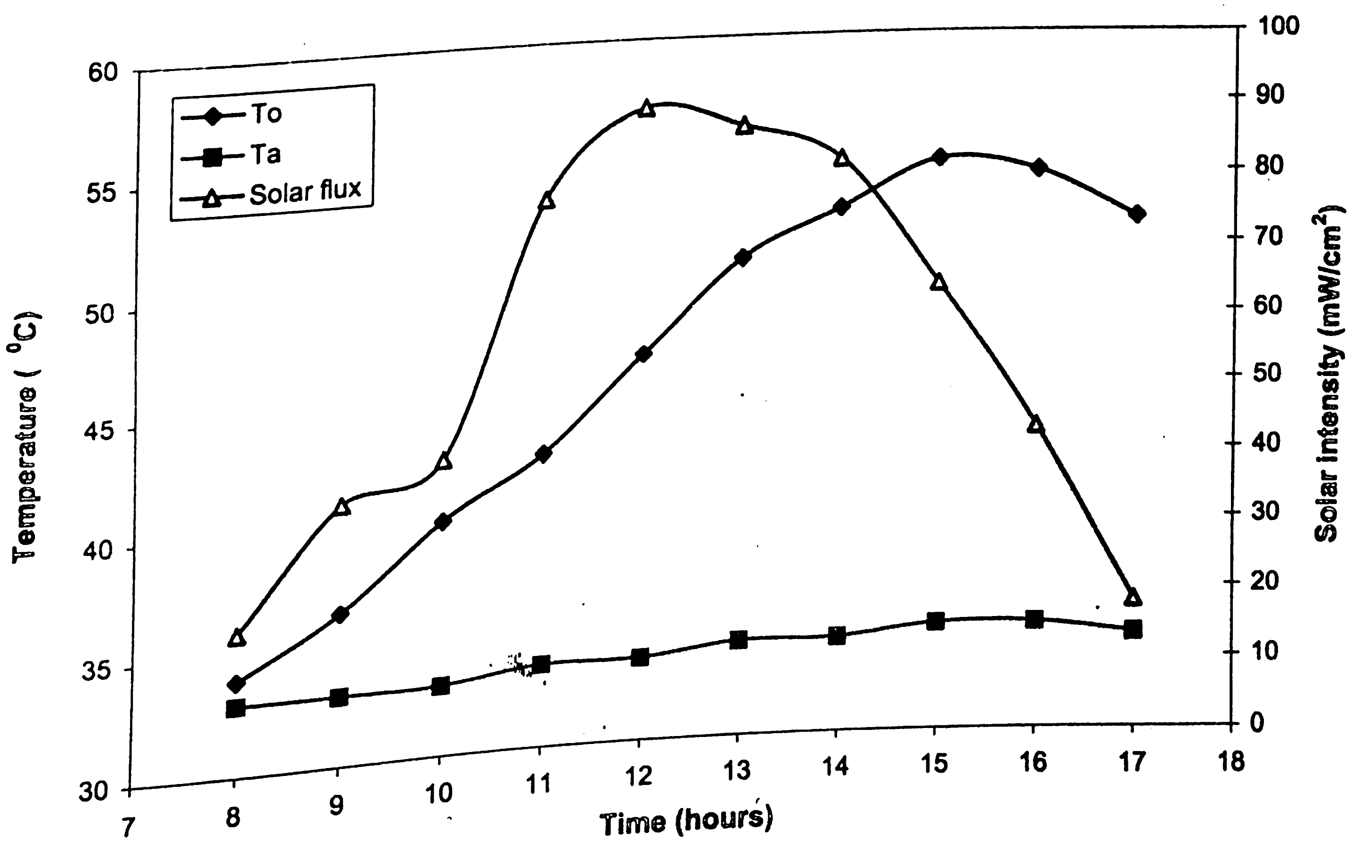


Fig. 17. Performance of solar water heater V ($SWH_{9.0}$) on 24-04-'98

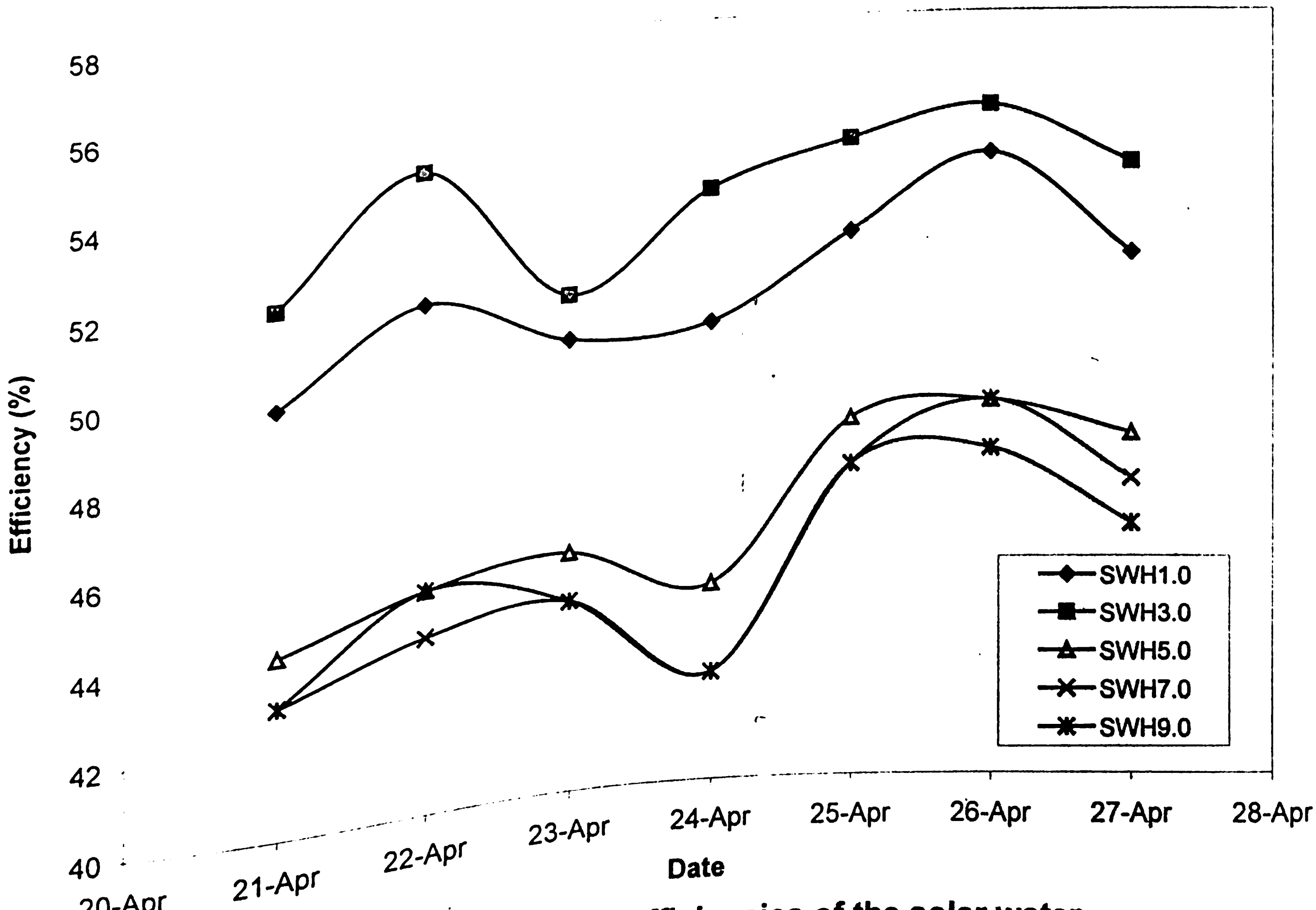


Fig.18. Comparison of efficiencies of the solar water heaters under the first test condition

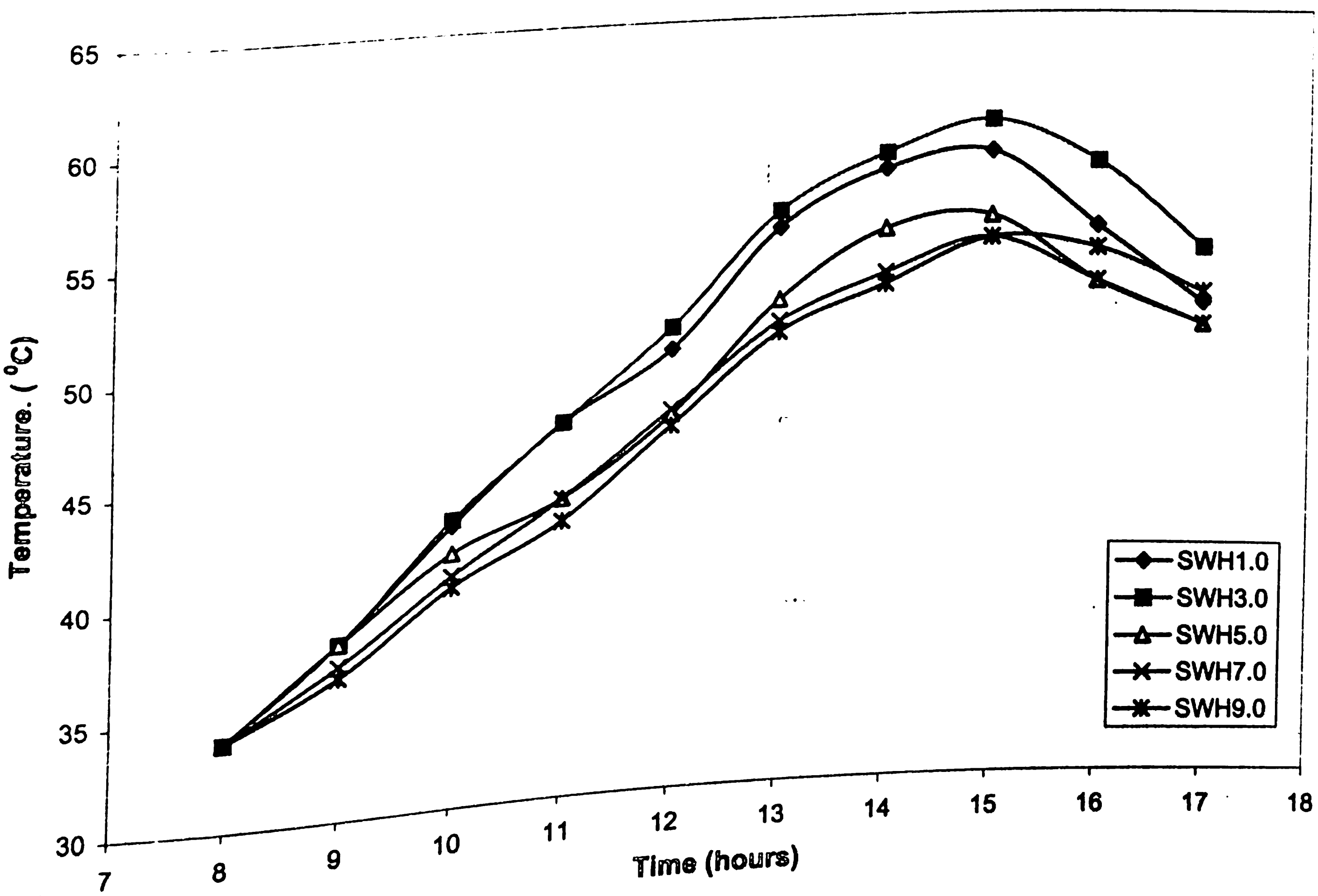


Fig.19. Comparison of outlet temperatures of the solar water heaters on 24-04-'98

absorber plate was only 1cm, and also by less efficient heat energy transfer to the water at the bottom. The low efficiency of $SWH_{5.0}$, $SWH_{7.0}$ and $SWH_{9.0}$ compared to $SWH_{3.0}$ might be because of the higher gap between the top glass cover and the absorber plate, i.e. 5,7, and 9 cm respectively.

4.1.2 Solar water heaters tested under the second test condition

The performance of the solar water heaters under the second test condition i.e. water heaters were filled with water at every 1 h interval from 8am to 5pm, is discussed below

Performance of solar water heater I ($SWH_{1.0}$)

The average solar radiation, ambient temperature, inlet temperature and outlet temperature at 12noon and the daily efficiency of this solar water heater are presented in Table 7. A maximum efficiency of 31.87% and a maximum outlet temperature of 50^{0}C were obtained on 3-05-'98. The relevant parameters of the solar water heaters on a clear sunny day during the experiment are shown in Appendix IV. It is clear from the observation that the outlet temperature increased to the maximum value at about 12noon and then it decreased. The highest solar intensity was also noted at 12noon. The continuous performance of the solar water heater on 28-04-'98 is shown in Fig.20. A maximum outlet temperature of 53^{0}C was obtained on different days at 12noon.

Table 7. Daily average solar radiation, inlet, outlet and ambient temperatures, and efficiency of solar heater I ($SWH_{1.0}$) under the second test condition from 8 to 17 hours

Date	Average solar radiation (W/m^2)	Average ambient temperature (^0C)	Inlet temperature (^0C)	Outlet temperature (^0C)	Efficiency (%)
28-04-'98	574	34.20	35	49.5	29.38
29-04-'98	585	34.10	35	49.5	28.83
30-04-'98	579	34.25	35	49.0	28.12
01-05-'98	581	34.65	35	49.0	28.03
02-05-'98	578	34.25	34	49.5	31.19
03-05-'98	584	33.85	34	50.0	31.87
04-05-'98	586	34.00	34	49.5	28.78

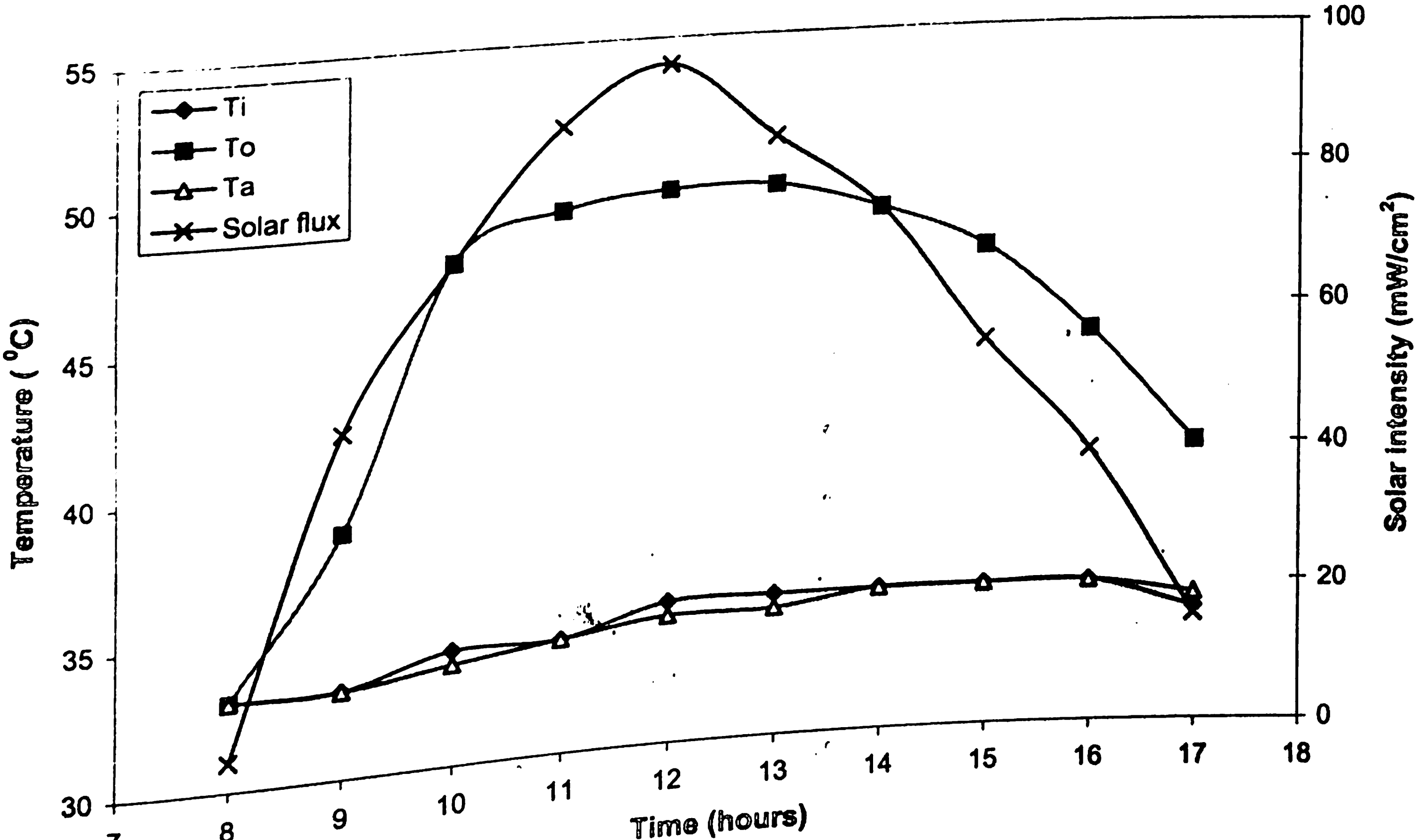


Fig. 20. Performance of solar water heater I ($SWH_{1.0}$) on 28-04-'98

Performance of solar water heater II ($SWH_{3.0}$)

The performance of $SWH_{3.0}$ is shown in Table 8. From the table it was observed that maximum efficiency of 31.87% and maximum average outlet temperature of 50^0C at 12noon were obtained on 3-05-'98. The performance of the solar water heater on 28-04-'98 is tabulated in Appendix IV and presented in Fig.21. It is clear that maximum outlet temperature of 51^0C at 12noon was obtained on different days.

Performance of solar water heater III ($SWH_{5.0}$)

It is clear from the Table 9 that the maximum efficiency of 27.88% and maximum average outlet temperature of 48^0C were obtained on 3-05-'98. The performance of the solar water heater on a clear sunny day is presented in Appendix IV. Fig. 22 shows the variation of the inlet, outlet and ambient temperatures, and solar radiation on 28-04-'98. The maximum temperature developed by the $SWH_{5.0}$ was 49^0C at 12noon on 3-05-'98.

Performance of solar water heater IV ($SWH_{7.0}$)

Performance details of solar water heater III is presented in Table 10. The maximum efficiency of 25.89% and maximum average outlet temperature of 47^0C at 12noon were obtained on 3-05-'98. The performance of $SWH_{7.0}$ on a clear sunny day is shown in Fig. 23. The maximum outlet temperature recorded was 48^0C at 12noon on 3-05-'98.

Table 8. Daily average solar radiation, inlet, outlet and ambient temperatures, and efficiency of solar heater II ($SWH_{3.0}$) under the second test condition from 8 to 17 hours

Date	Average solar radiation (W/m^2)	Average ambient temperature (^0C)	Inlet temperature (^0C)	Outlet temperature (^0C)	Efficiency (%)
28-04-'98	574	34.20	35	48.5	27.35
29-04-'98	585	34.10	35	49.5	28.83
30-04-'98	579	34.25	35	49.0	28.12
01-05-'98	581	34.65	35	48.5	27.03
02-05-'98	578	34.25	34	49.5	31.19
03-05-'98	584	33.85	34	50.0	31.87
04-05-'98	586	34.00	34	49.0	27.79

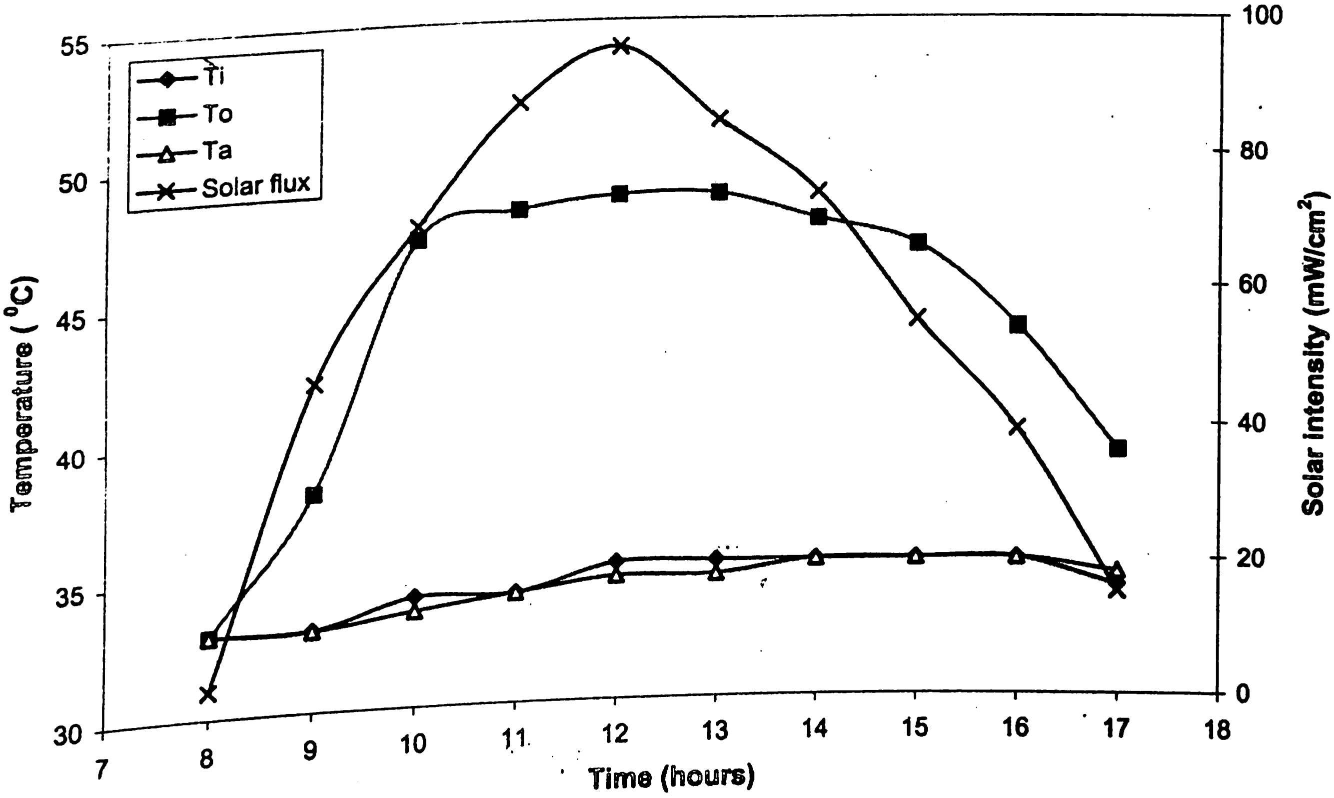


Fig. 21. Performance of solar water heater II ($SWH_{3.0}$) on 28-04-'98

Table 9. **Daily average solar radiation, inlet, outlet and ambient temperatures, and efficiency of solar heater III ($SWH_{5.0}$) under the second test condition from 8 to 17 hours**

Date	Average solar radiation (W/m^2)	Average ambient temperature (^{0}C)	Inlet temperature (^{0}C)	Outlet temperature (^{0}C)	Efficiency (%)
28-04-'98	574	34.20	35	46.5	23.30
29-04-'98	585	34.10	35	46.5	23.86
30-04-'98	579	34.25	35	46.0	22.10
01-05-'98	581	34.65	35	46.5	23.02
02-05-'98	578	34.25	34	46.5	21.15
03-05-'98	584	33.85	34	48.0	27.88
04-05-'98	586	34.00	34	47.0	23.82

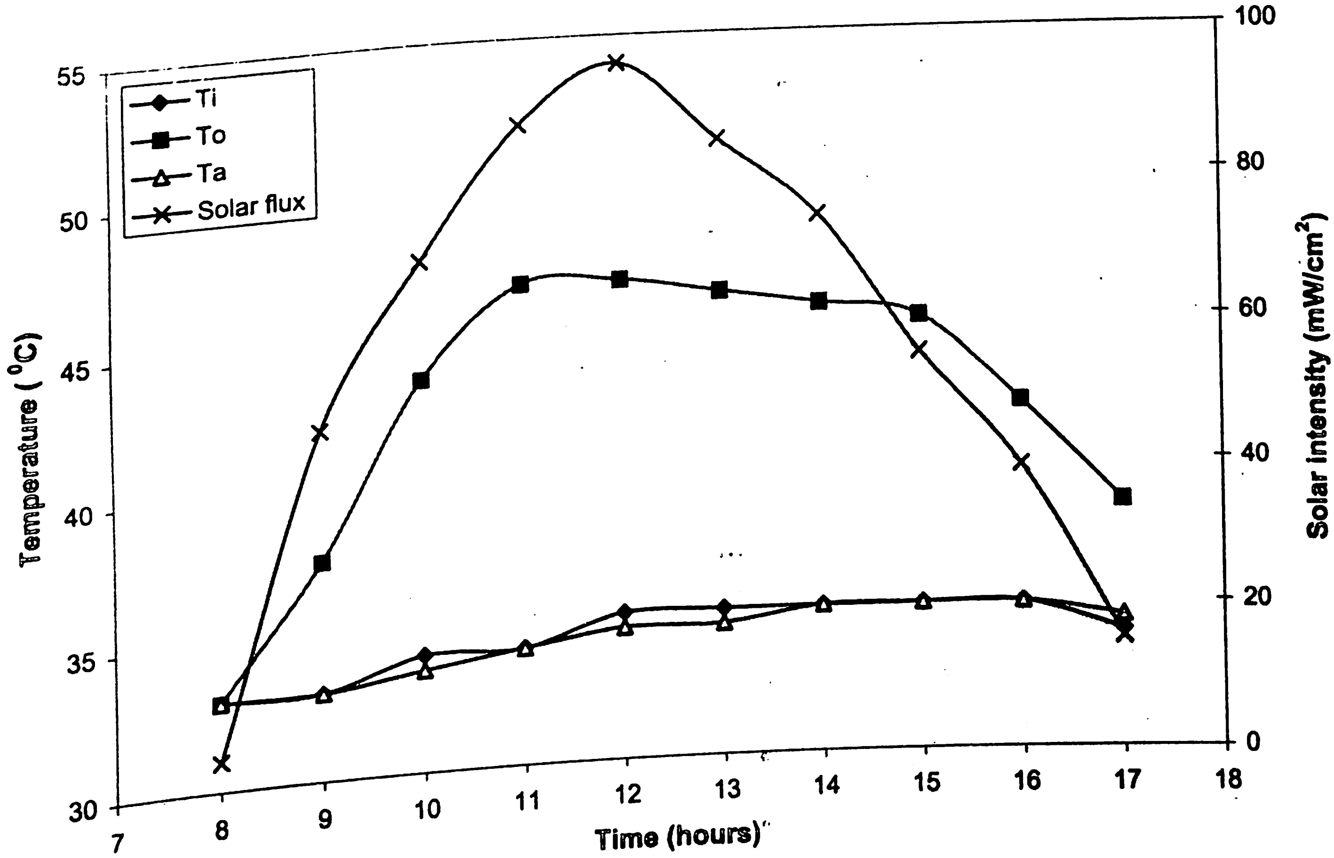


Fig. 22. Performance of solar water heater III ($SWH_{5.0}$) on 28-04-'98

Table 10. Daily average solar radiation, inlet, outlet and ambient temperatures, and efficiency of solar heater IV ($SWH_{7.0}$) under the second test condition from 8 to 17 hours

Date	Average solar radiation (W/m^2)	Average ambient temperature (^0C)	Inlet temperature (^0C)	Outlet temperature (^0C)	Efficiency (%)
28-04-'98	574	34.20	35	46.5	23.30
29-04-'98	585	34.10	35	46.5	23.86
30-04-'98	579	34.25	35	46.0	22.10
01-05-'98	581	34.65	35	45.5	21.02
02-05-'98	578	34.25	34	46.0	24.15
03-05-'98	584	33.85	34	47.0	25.89
04-05-'98	586	34.00	34	46.5	22.83

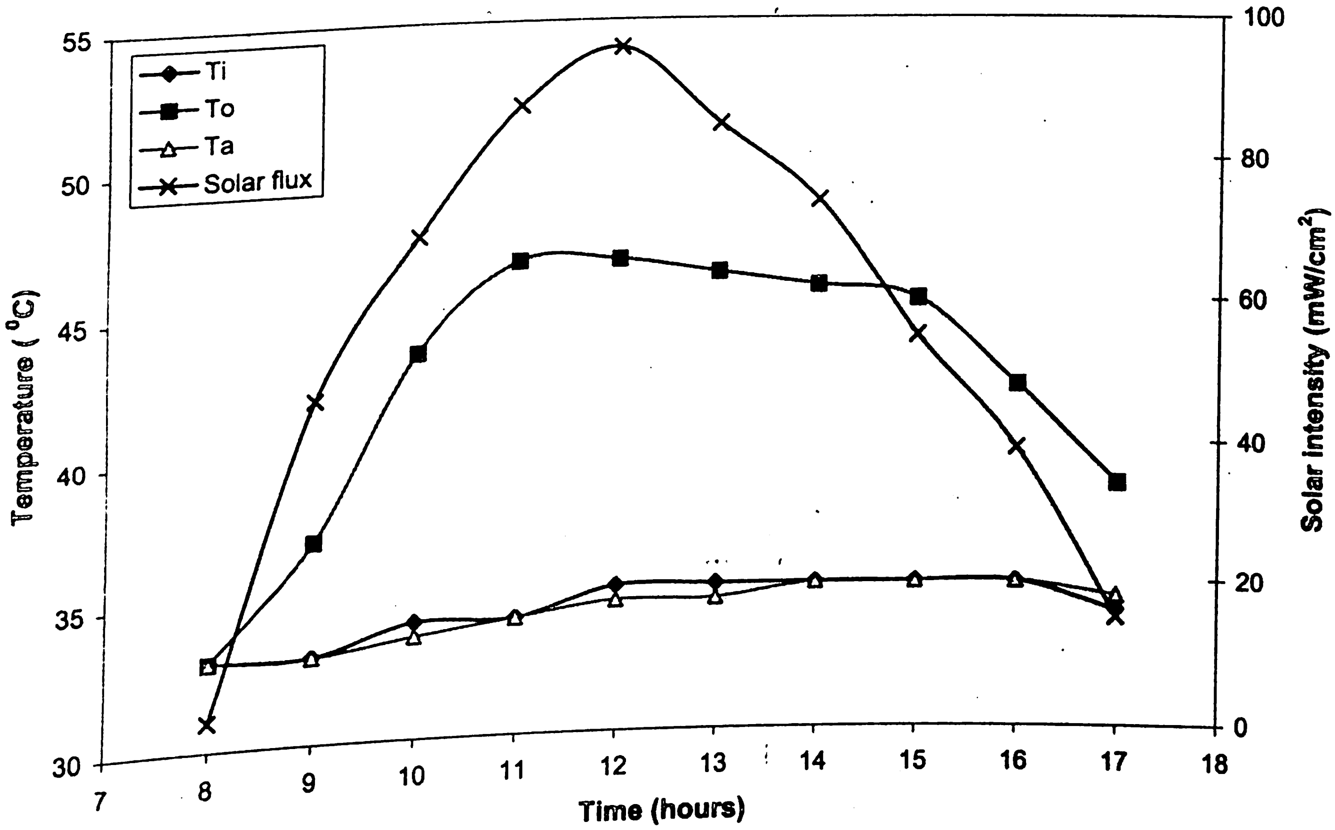


Fig. 23. Performance of solar water heater IV ($SWH_{7.0}$) on 28-04-'98

Performance of solar water heater V ($SWH_{9.0}$)

Table 11 shows that maximum efficiency of 25.89% was obtained on 3-05-'98 for the solar water heater . The maximum average outlet temperature of 47^0C at 12noon was obtained on different days during the experiment. The performance of the $SWH_{9.0}$ on 28-04-98 is shown in Fig.24 and Appendix IV gives the data tabulated on the same day.

4.1.2.1 Comparative evaluation of the performance of the solar water heaters under the second test condition

The daily efficiencies of the solar water heaters during the experiment period are shown in Fig.25. It is obvious from the figure that the variation in efficiencies of $SWH_{1.0}$ and $SWH_{3.0}$ were very minimum. The maximum efficiencies obtained by $SWH_{1.0}$ and $SWH_{3.0}$ were same. The performance of $SWH_{1.0}$ and $SWH_{3.0}$ were good as compared to $SWH_{5.0}$, $SWH_{7.0}$ and $SWH_{9.0}$. The efficiency of $SWH_{5.0}$ was slightly higher than that of $SWH_{7.0}$ and $SWH_{9.0}$. The variation in efficiencies of $SWH_{7.0}$ and $SWH_{9.0}$ are less. Fig. 26 shows the variation in outlet temperatures of the solar water heaters in a clear sunny day. It was clear from the figure that the outlet temperatures obtained by $SWH_{1.0}$ and $SWH_{3.0}$ outperforms the other solar water heaters tested. The variation in the outlet temperatures developed by $SWH_{5.0}$, $SWH_{7.0}$ and $SWH_{9.0}$ were minimum. The reasons for the variation in the performance of the solar water heaters might be the same explained under section 4.1.1.1 earlier.

Table 11. Daily average solar radiation, inlet, outlet and ambient temperatures, and efficiency of solar heater V ($SWH_{9.0}$) under the second test condition from 8 to 17 hours

Date	Average solar radiation (W/m^2)	Average ambient temperature (^{0}C)	Inlet temperature (^{0}C)	Outlet temperature (^{0}C)	Efficiency (%)
28-04-'98	574	34.20	35	47.0	24.32
29-04-'98	585	34.10	35	47.0	23.86
30-04-'98	579	34.25	35	46.0	22.10
01-05-'98	581	34.65	35	45.5	21.02
02-05-'98	578	34.25	34	46.5	25.15
03-05-'98	584	33.85	34	47.0	25.89
04-05-'98	586	34.00	34	46.5	22.83

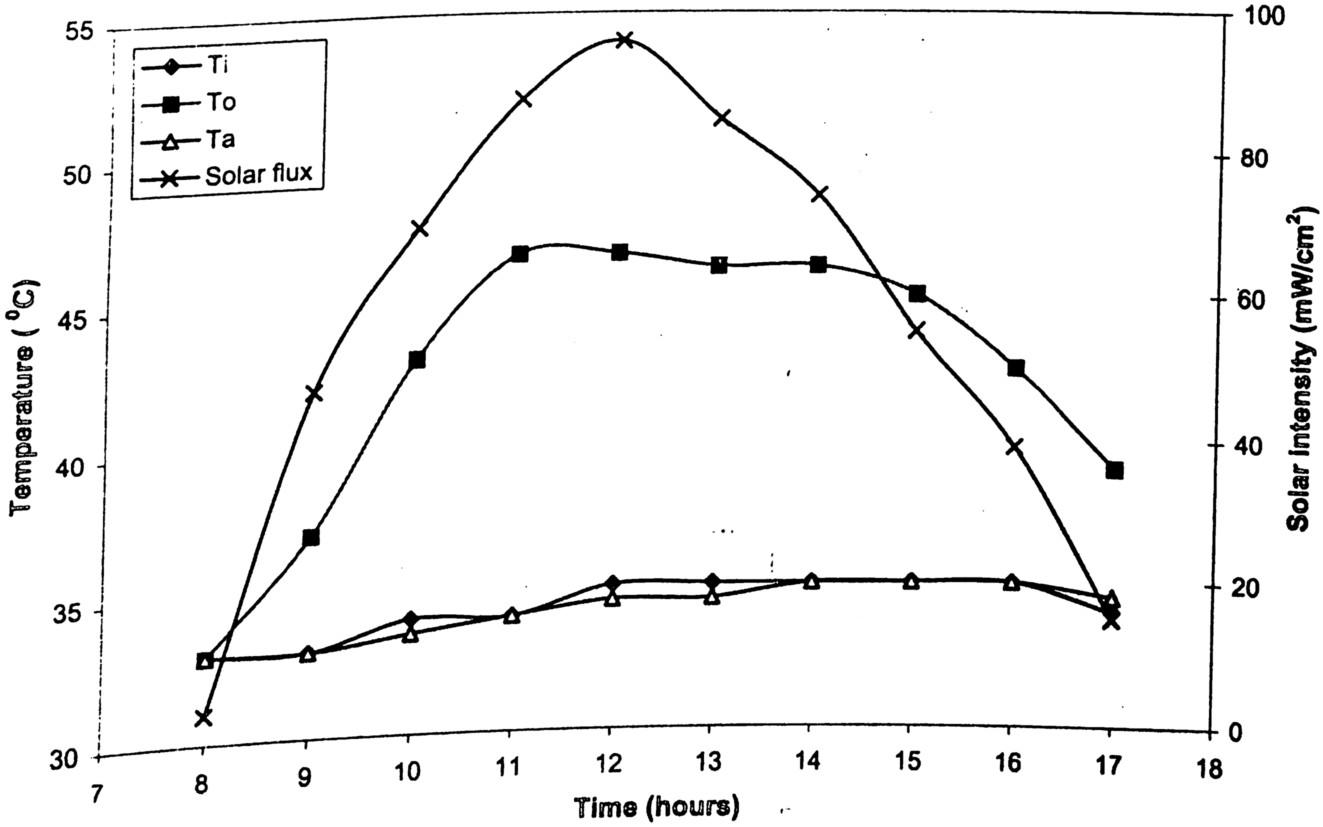


Fig. 24. Performance of solar water heater V ($SWH_{9.0}$) on 28-04-'98

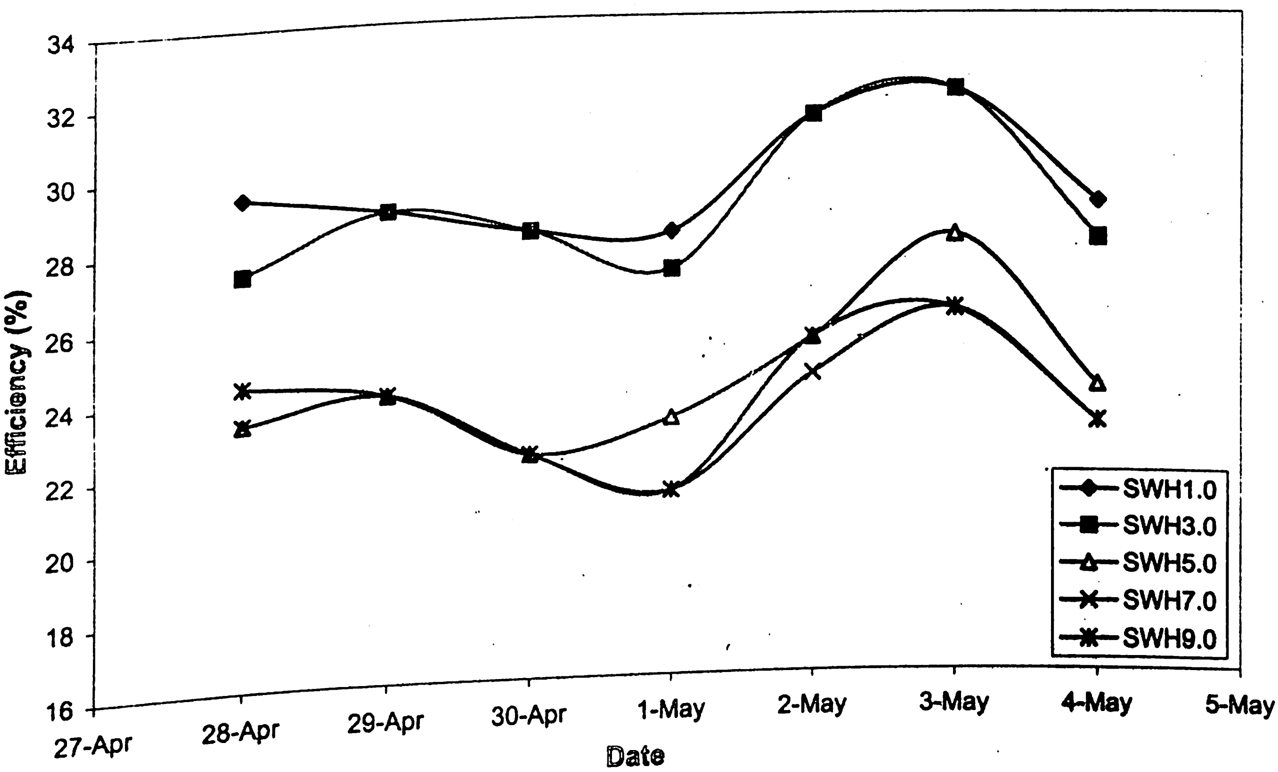


Fig. 25 Comparison of efficiencies of the solar water heaters under second test condition

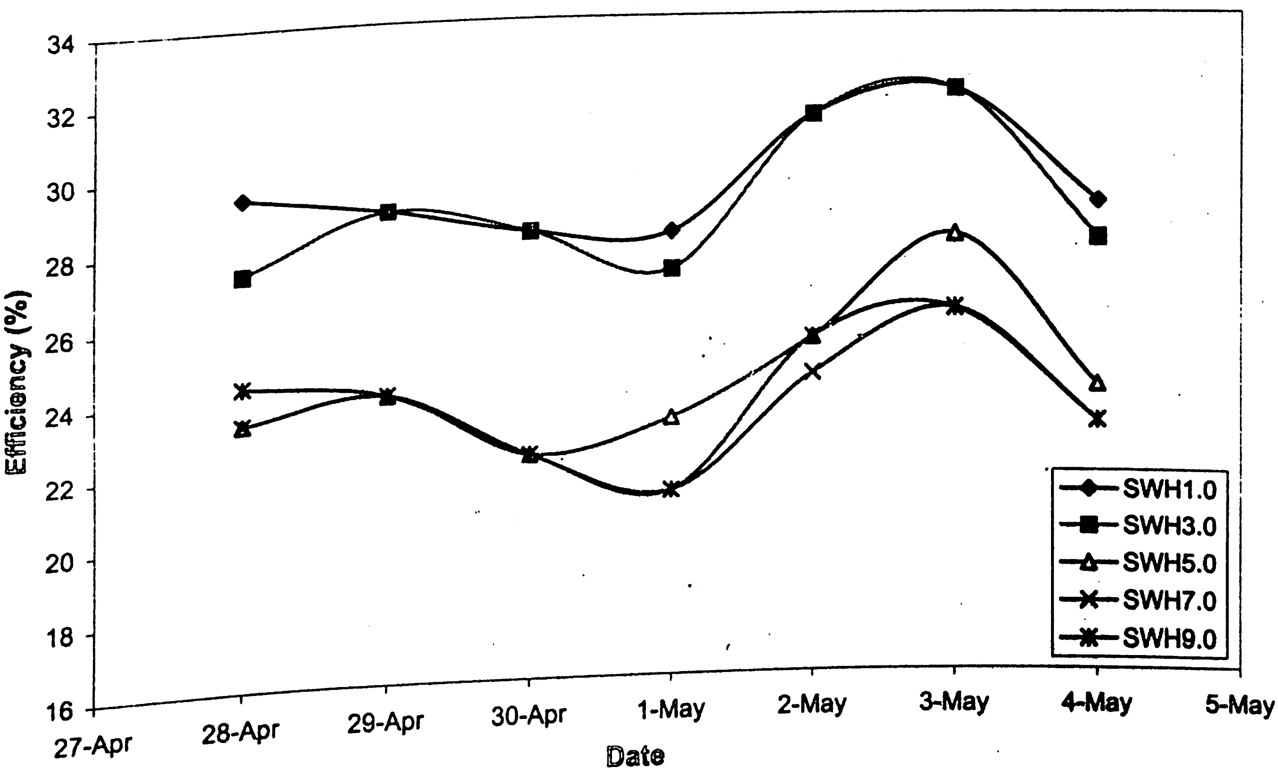


Fig. 25 Comparison of efficiencies of the solar water heaters under second test condition

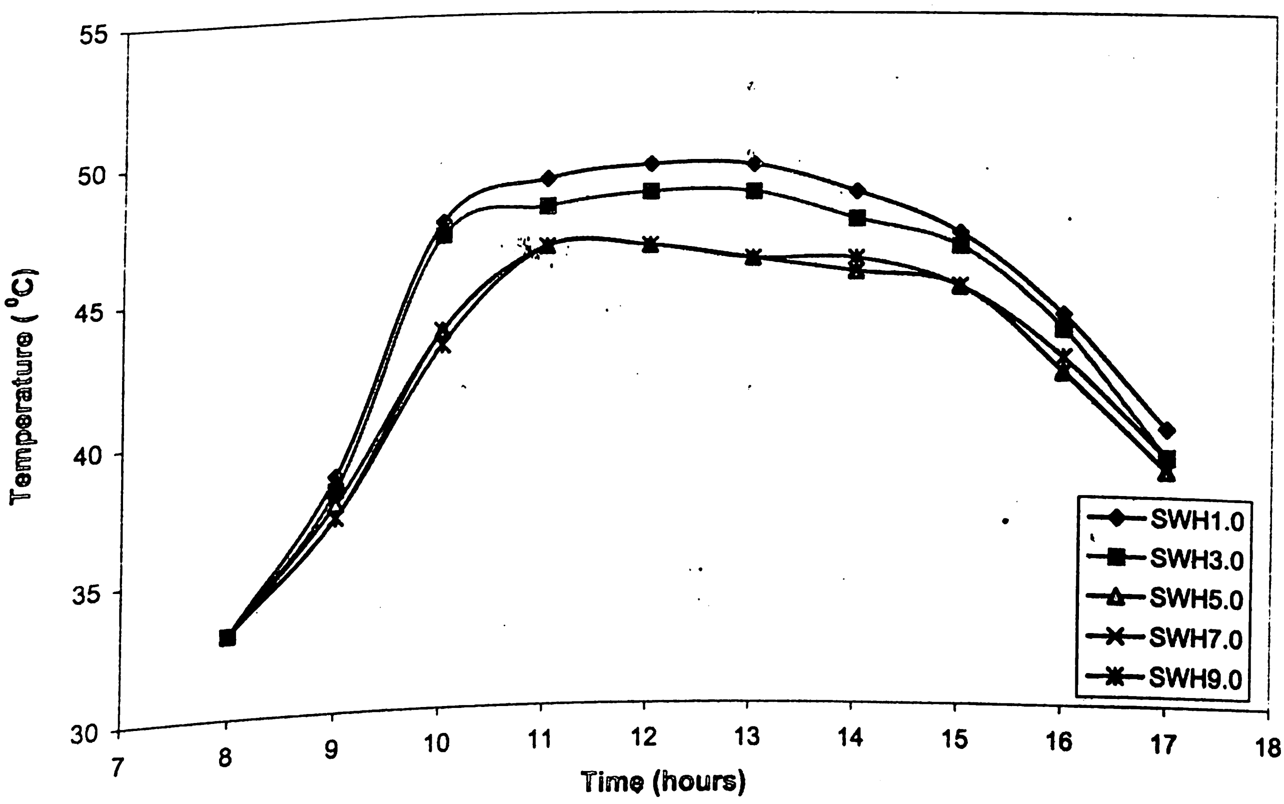


Fig. 26. Comparison of outlet temperatures of the solar water heaters on 28-04-'98

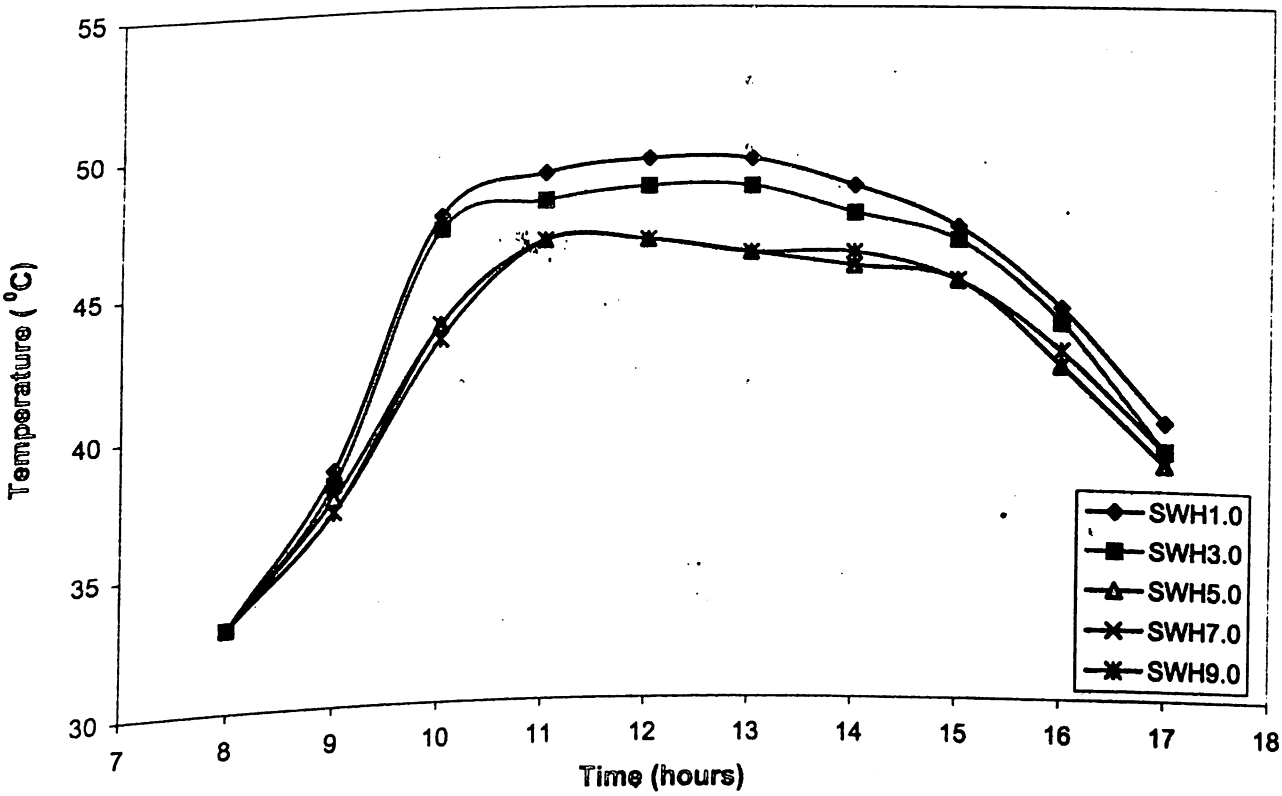


Fig. 26. Comparison of outlet temperatures of the solar water heaters on 28-04-'98

4.2 Economics of the solar water heaters

The solar water heaters comprised fibre glass storage tank, blackened aluminium collectors and plain glass cover. There was only slight variation in the total cost for the production of solar water heaters. This slight variation occurred due to the fact that the quantity of aluminium sheet used for different models were different. The solar water heater can provide 30 litres of hot water from 9am onwards and this can be used for cooking, cleaning of utensils and similar other domestic use. The total cost of each solar water heater worked out to be Rs 1000/- and the operating cost per unit of thermal energy obtained with the heater is found to be 25 paise per kWh. The details of cost analysis are presented in Appendix V.

4.3 Handling of the solar water heaters

The weight of the empty solar water heater was about 9.5kg. This weight is small enough to handle the solar water heater easily by one person. The solar water heater can be transported to any place by one person. The installation of the heater can also be done by a single person due to its light weight.

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Summary and Conclusion

SUMMARY AND CONCLUSION

Solar radiation is a dependable energy source, as against the dwindling fossil fuels. It is clean and can be tapped with moderate skill and technology. Water heating is a simple and low cost application of solar energy. The conventional solar water heaters are costly and inefficient due to higher thermal losses. A Collector-cum-storage type solar water heater was designed and fabricated with fibre reinforced plastic tank, aluminium absorber plate and glass cover, to reduce the thermal losses, thereby increasing the efficiency, and reduce the initial cost. It had an overall dimension of 67 x 47 x 10 cm, capacity of 30 litres and a collector area of 0.3 m^2.

The five versions of the solar water heaters all without thermal insulation were tested under two different test conditions: the first with stagnant water and the second with hourly replacement of water both from 8am to 5pm, and the results are summarized below:

1. **Solar water heater I ($SWH_{1.0}$)**

   a) Maximum efficiency of 54.56% was observed under the first test condition
   b) Maximum efficiency of 31.87% was observed under the second test condition
   c) Maximum temperature of 64^0C was noted at 3pm

2. **Solar water heater II ($SWH_{3.0}$)**

   a) Maximum efficiency of 55.72% was observed under the first test condition
   b) Maximum efficiency of 31.87% was observed under the second test condition
   c) Maximum temperature of 61^0C was noted at 3pm

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3. **Solar water heater III ($SWH_{5.0}$)**

a) Maximum efficiency of 48.75% was observed under the first test condition

b) Maximum efficiency of 27.88% was observed under the second test condition

c) Maximum temperature of 58^{0}C was noted at 3pm

4. **Solar water heater IV ($SWH_{7.0}$)**

a) Maximum efficiency of 48.75% was observed under the first test condition

b) Maximum efficiency of 25.89% was observed under the second test condition

c) Maximum temperature of 57^{0}C was noted at 3pm

5. **Solar water heater V ($SWH_{9.0}$)**

a) Maximum efficiency of 47.59% was observed under the first test condition

b) Maximum efficiency of 25.89% was observed under the second test condition

c) Maximum temperature of 56^{0}C was noted at 3pm

From the performance of the solar water heaters we could conclude that

1. A maximum outlet temperature was 64^{0}C at 3pm
2. A maximum efficiency of 55.72% was obtained at 3pm in solar water heater II ($SWH_{3.0}$)
3. The optimum position of the absorber plate was 3cm from the top glass plate, i.e. in solar water heater II ($SWH_{3.0}$)
4. The solar water heater supplies heat energy at 25 paise per kWh, which is about 4 times less than the prevailing electricity rates in India

The following suggestions are made for further improvement of the solar water heater:

1. An automatic tilting mechanism to be provided to track the sun.
2. An outer box with insulation may be provided. This will increase efficiency and aid easy handling.
3. An additional glass plate may be provided to increase the efficiency of the solar water heater.
4. Use selective surface to increase efficiency.

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* Originals not seen

Appendices

Appendix I

a) Thermal conductivity of common materials for solar water heater

Material	Coefficient of thermal conductivity (cal/h cm^{0}C)
Aluminium Sheet	117.00
Glass	0.44
Air	0.014
Water	5.314
GI	79.40
MS	46.10

b) Properties of fibre glass

1. Density	–	1.8 g/cc
2. Thermal conductivity	–	0.0196 cal/h /cm^{0}C
3. Tensile strength	–	700 N/mm^2
4. Compressive strength	–	1200 N/mm^2
5. Bending strength	–	1400 N/mm^2
6. Modulus of elasticity	–	33,000 N/mm^2

Appendix II

Instrumentation

A) Specification of solar intensity meter

Name	:	Surya mapi
Model No.	:	SM 201
Range	:	0-120 mW/cm^2, AMI radiation
Supplied	:	Central Electronics Ltd.

B) Specification of thermometer

Make	:	Pensky Mar tens, England
Range	:	0-110^{0}C

Appendix III. Solar intensity, outlet and ambient temperatures of the solar water heaters during 1 hour intervals on 24-04-'98 under the first test condition

Time	Temperatures (⁰C)					Solar intensity (W/m²)	Ambient temperature (⁰C)
	$SWH_{1.0}$	$SWH_{3.0}$	$SWH_{5.0}$	$SWH_{7.0}$	$SWH_{9.0}$		
	To	To	To	To	To		
8am	34.00	34.0	34.0	34.00	34.0	200	33.0
9am	38.00	38.0	38.0	37.00	36.5	370	33.0
10am	42.75	43.0	41.5	40.50	40.0	420	33.0
11am	47.50	47.0	43.5	43.50	42.5	780	33.5
12noon	50.00	51.0	47.0	47.25	46.5	900	33.5
1pm	55.25	56.0	52.0	51.00	50.5	870	34.0
2pm	57.75	58.5	55.0	53.00	52.5	820	34.0
3pm	58.50	60.0	55.5	54.50	54.5	640	34.5
4pm	55.00	58.0	52.5	52.50	54.0	430	34.5
5pm	51.50	54.0	50.5	50.50	52.0	180	34.0

* Inlet temperature, Ti = 34⁰C

Appendix IV. Solar intensity, inlet, outlet and ambient temperatures of the solar water heaters during 1 hour intervals on 28-04-'98 under the second test condition

Time	Temperatures (^0C)										Solar intensity (W/m^2)	Ambient temperature (^0C)
	$SWH_{1.0}$		$SWH_{3.0}$		$SWH_{5.0}$		$SWH_{7.0}$		$SWH_{9.0}$			
	Ti	To	Ti	To	Ti	To	Ti	To	Ti	To		
8am	33	33.0	33	33.0	33	33.0	33	33.0	33	33.0	40	33.0
9am	33	38.5	33	38.0	33	37.5	33	37.0	33	37.0	480	33.0
10am	34	47.5	34	47.0	34	43.5	34	43.5	34	43.0	700	33.5
11am	34	49.0	34	48.0	34	46.5	34	46.5	34	46.5	880	34.0
12noon	35	49.5	35	48.5	35	46.5	35	46.5	35	46.5	960	34.5
1pm	35	49.5	35	48.5	35	46.0	35	46.0	35	46.0	850	34.5
2pm	35	48.5	35	47.5	35	45.5	35	45.5	35	46.0	740	35.0
3pm	35	47.0	35	46.5	35	45.0	35	45.0	35	45.0	550	35.0
4pm	35	44.0	35	43.5	35	42.0	35	42.0	35	42.5	390	35.0
5pm	34	40.0	34	39.0	34	38.5	34	38.5	34	39.0	150	34.5

Appendix V

Operating cost of the solar water heater

1. Assumptions

Life of the solar water heater, L	=	20 years
Maintenance	=	5% of the capital cost
Interest, i	=	7% of the capital cost
Solar radiation received during the year	=	1800 kWh/m^2

2. Calculations

Cost of materials used for the fabrication of the solar water heaters (5 nos.)

Sl. No.	Materials	Quantity	Cost
1	Fibre glass trough	5 nos.	Rs. 4875/-
2	Aluminium collector	5 nos.	
3	Glass cover	5 nos.	
4	Labour charge	5 nos.	
5	Black board paint	1/2 litres	Rs. 150/-

Total = Rs. 5025/-

Cost of one solar water heater, C = 5025/5 ≈ Rs. 1000/-

Life, L = 20 years

Solar radiation received / year / 0.3m^2, H = 1800 x 0.3 = 540 kWh

a) Depreciation per kWh = (0.9 x C) / (L x H)

= (0.9 x 1000) / (20 x 540) = Rs. 0.083/-

b) Interest per kWh = (0.55 x C x i) / H

= 0.55x1000x7) / (540x100) = Rs. 0.0713/-

C) Maintenance = (1000 x 5) / (540 x 100) = Rs. 0.0926/-

Total operating cost per kWh = Rs. 0.2472/- ≈ Rs. 25 paise

DEVELOPMENT AND TESTING OF A COLLECTOR-CUM-STORAGE TYPE SOLAR WATER HEATER FOR DOMESTIC USE

By

BIJUKUMAR, K.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Technology in Agricultural Engineering

Faculty of Agricultural Engineering & Technology
Kerala Agricultural University

Department of Farm Power Machinery & Energy
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
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2000

ABSTRACT

The present study was undertaken to design and develop a collector-cum-storage type solar water heater of 30 litre capacity to supply hot water for domestic use.

Five solar water heaters with different absorber plate positions were constructed. The storage tanks with dimensions of 67 x 47 x 10 cm were made by using fibre glass, and the top of these storage tanks were covered using single plain glass plates of 71 x 51 x 0.4 cm size. The position of the absorber plate was varied by changing the width of the spacers (4 nos. at an angle of 40^0 with the side aluminium sheet), which connects bottom aluminium plate and top absorber plate. The absorber plate was of 65 x 45 cm size. The top face of the absorber plate was painted black to absorb maximum solar radiation. The absorber plate positions were 1cm, 3cm, 5cm, 7cm and 9cm from the top glass cover plate and were designated as $SWH_{1.0}$, $SWH_{3.0}$, $SWH_{5.0}$, $SWH_{7.0}$ and $SWH_{9.0}$ respectively.

The absorber plate position was optimized by testing the solar water heaters under two different test conditions. Solar water heater II ($SWH_{3.0}$) outperforms other solar water heaters under the two test conditions. Maximum outlet temperature of 64^0C at 3pm and maximum efficiency of 55.72% also at 3pm were observed in solar water heater II. So it is optimized that the position of the absorber plate should be at 3cm from the top glass plate. The solar water heater can easily be handled by a single person since the weight is only 9.5kg. The operating cost per unit of thermal energy obtained with the solar water heater was found to be 25 paise per kWh.