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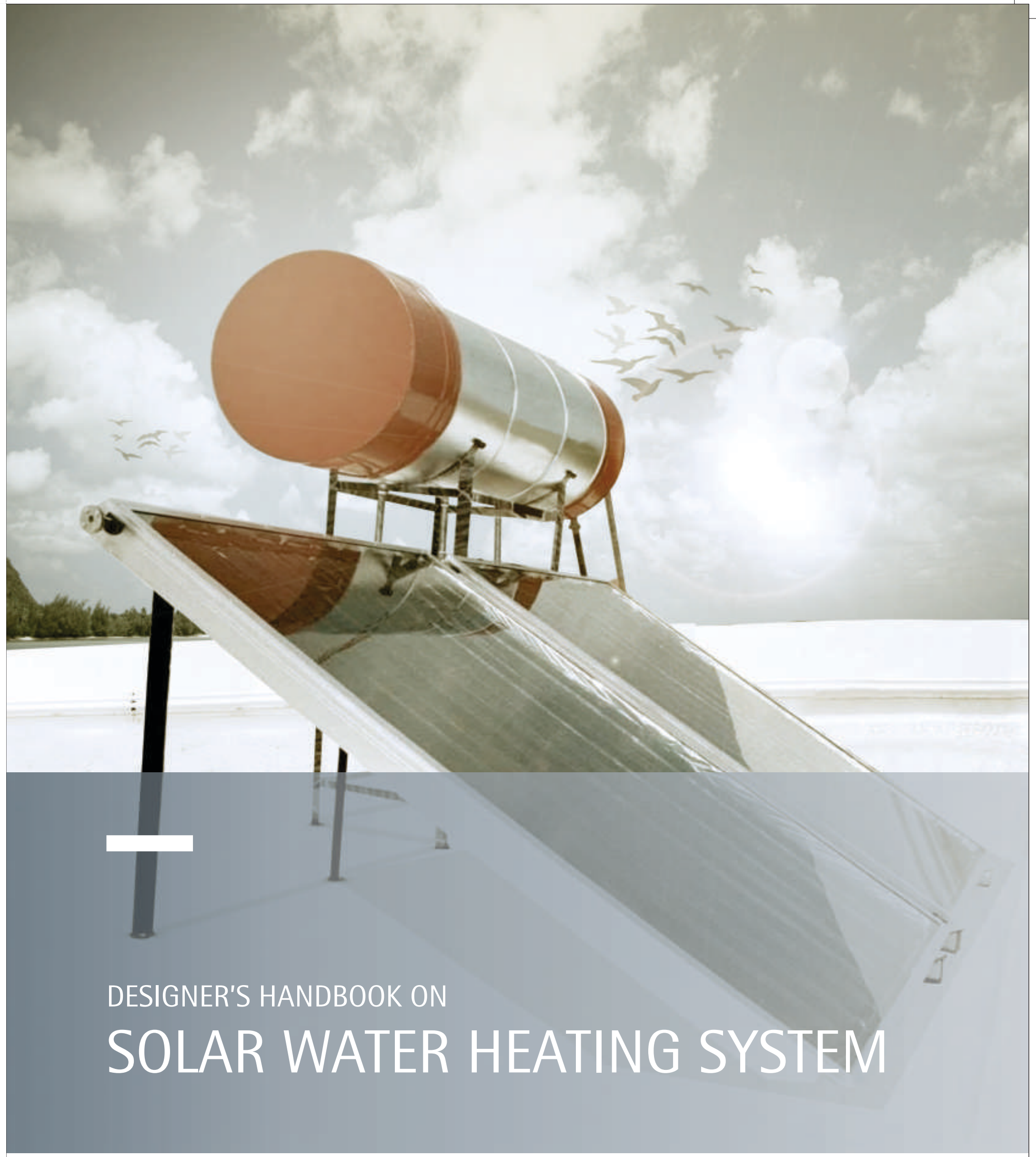

DESIGNER'S HANDBOOK ON

# SOLAR WATER HEATING SYSTEM

International Copper Promotion Council India
Copper Alliance

UNDP India MNRE GEF

# Contents




# Contents

# Preface

The use of hot water for bathing and other purposes has become anintegral part of modern lifestyles. With the abundant availability ofsunlight in our country, even in colder regions, solar water heating is anatural solution. It has been established that the investment insolarwater heaters pays itself back through saved electricity costs in 4 to 5years and hereafter the hot water becomes available for free over thelifetime of the equipment of more than 15 years. Governmentsubsidized loans are available to finance the equipment costs.

With this background it is anticipated that the market of Solar Water Heaters & Systems will increase. With this the need for proper & good quality Systems will become the order of the day. Hence, development of the Designing skill of Designers of Solar Water Heaters & Systems has been identified as one of the Key activities for the supply chain. The gap in such skills brings uncalled for bad name to the Industry at large.

It is to address this need, that International Copper PromotionCouncil India, as a part of Global Market Transformation Project of UNDP / GEF in partnership with MNRE,has taken the initiative in bringing out a brief handbook for Designers of Solar Water Heating Systems.

We hope that users will find this handbook of value.

SANJEEV RANJAN
CHIEF EXECUTIVE OFFICER
ICPCI

Place : Mumbai



# Introduction

The Ministry of New and Renewable Energy (MNRE), Government of India has joined hands with UNDP/UNEP/GEF in a project for Transformation and Strengthening of Market for Solar Water Heating Systems in India. International Copper Promotion Council (India) has been participating in this project and it has sponsored writing of this book. I am thankful to MNRE, UNDP/GEF and ICPCI who entrusted me with this assignment.

I have been involved in the designing and installation of solar water heating systems since 1978 when the solar water heating systems were in the initial stages of use in the country. I also had the opportunity of working with learned professionals like Dr R.K.Suri of BHEL and Dr V.G. Bhide of NPL. I also had the opportunity to interact with Dr C.L. Gupta, Professor M.S. Sodha, Dr S SMathur, Prof H P Garg, Dr N K Bansal, Prof S C Mullick and Dr R L Sawney. Dr Sawney has helped me in writing the book and has also reviewed it. Without encouragement from these learned people and their help it would not have been possible for me to indulge in design-experiments in solar water heating systems for the companies that I worked for, and also for the companies to whom I provided consultancy in the designing of these systems. These companies also encouraged me by having confidence in my designs and implementing these designs. I am grateful to all these companies for providing me the opportunity of experimenting at their cost and risk.

The small size solar water heating systems are used by the domestic users. The institutions and industries are users of large solar water heating systems. The strengthening of the market is possible if all such systems are designed and built to meet the specific requirements of these users.

This book has been written to help designers and installers of the solar water heating systems to understand the requirements of the users and build solar water heating systems that meet these requirements.

The book has been written for use by professionals engaged in designing and installing of solar water heating systems, or the new entrants into this profession. The writer therefore presumes that the users of the book will be familiar with technical vocabulary and therefore only the specific terms used in solar water heating systems design have been defined.

In writing of this book I have followed a simple approach that the solar water heating system must be treated as a system. The system has inputs in the form of solar radiation and cold water and the whole system operates on these inputs to deliver hot water to the users in the form and manner as per their requirements.

The professionals engaged in the design and installations of these systems have to understand the input and the output requirements of the solar water heating systems. Therefore the first few chapters of the book are devoted to develop the understanding of the inputs to the system and the output requirements of the users.

The next set of chapters is devoted to developing the understanding of the components that form the system. The understanding of these components helps in arranging these components in a manner that the output from the system is achievable. The role of each of these components and their behavior pattern has an important role to play in the delivery of the end results. The behavior of the components has been analysed and method of calculating this has also been explained.

Each component of the system has a role in the functioning of the system and each component has to operate in tandem with the other components of the system. In the designing of various types of systems for different applications, an attempt has been made to bring out this relationship. Finally a few examples of successful designs have been given.

It has been a firm belief of the author that properly designed and built Solar Water Heating systems can provide continuous service to users for periods in excess of 30 years with some amount of regular maintenance.

I hope this book will help designers and installers of the solar water heating systems in building systems which satisfy the requirements of the users and thus promote the use of these systems.

ATAM KUMAR

Independent Consultant,
Solar Water Heating Systems

Place: New Delhi



# Acknowledgment

This Handbook is an effort to provide guidance to the Designers of Solar Water Heating Systems enabling them to select the right Technology, Materials, methods for setting up such Systems for the ultimate benefit of end users.

Many organizations and individuals have contributed significantly with their ideas and suggestions to shape up this hand book. The objective of this hand book would not have been completed without active supports of:

**The Ministry of New & Renewable Energy (MNRE)**

- Shri Gireesh B. Pradhan, Secretary
- Shri Tarun Kapoor, Joint Secretary
- Dr. A.K.Singhal - National Project Manager, UNDP/GEF Project
- Dr. Santram - Director
- Dr. S.K.Singh, Director, Solar Energy Center
- Dr. J.P.Singh, Director, Solar Energy Center
- Shri Pankaj Kumar, Dy. National Project Manager, UNDP/GEF Project

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- Dr. S. N. Srinivas
- Ms. Chitra Narayanswamy

**Copper Development Centre, Europe**

- Mr. Nigel Cotton

**ICPCI**

- Mr. Sanjeev Ranjan
- Mr. Virendra Gupta

Chapter 1

# Solar Radiation Data

### OBJECTIVE

The objective of this chapter is to introduce the terminology used in defining the solar radiation data. We shall also introduce the source of this data for places in India. This will also help in making use of the data for designing and installation of solar water heating systems.

### INTRODUCTION

The sun emits electromagnetic radiation all the time and a very small part of it is intercepted by the earth. Only the part the earth which is facing the sun receives the radiation at any point of time. Also the radiation reaching the earth surface is affected by the atmosphere. The earth's atmosphere contains various gases suspended solids dust and other liquids besides water vapor in gaseous form and in the form of clouds. The Solar radiation reaching the earth surface is depleted to some extent by passage through these elements. The reduction in this radiation is varying all the time and also it varies from place to place on the earth surface.

Besides the Earth revolves around the sun in an elliptical orbit of a small eccentricity .It completes one revolution in one year .The earth also revolves around its own axis and axis of this rotation is inclined at about 23.5 degree with respect to normal to the plane of orbital revolution. Because of this large variation occurs in the solar radiation received at different latitudes on the earth resulting in seasons on the earth. The rotation of the earth on its own axis causes the continuous variation of solar radiation on the surface as the inclination of the surface with respect to the solar radiation beam keeps changing all the time.

It therefore becomes necessary to have an idea of the amount of solar radiation available on a surface on earth to estimate the amount of energy that can be delivered by solar water heating system located in a particular area with its particular orientation. This information is called the solar radiation data for the particular place.

### SOLAR RADIATION DATA

The solar radiation before entering the earth's atmosphere is in the form a beam of radiation which covers a very large wavelength range from radio-waves, infrared waves, visible and ultraviolet light and X rays and gamma rays. However 99 % of this radiation is



in the form of near ultra violet, visible and infrared range. Before entering the earth's atmosphere the radiation is in the form of a beam of radiation. However after entering the atmosphere and its passage before it reaches the earth surface a part of this radiation is scattered by dust particles, water droplets and other suspended matter.

- The radiation that reaches the Earth's surface in a beam form is called direct solar radiation.
- The direct solar radiation which is received on a unit surface normal to the beam of radiation is called the Direct Solar Radiation at Normal Incidence. ($I_N$)
- Direct Solar radiation, which is received a horizontal surface, is the quantity of radiation received on a unit area on the surface parallel to the earth surface. ($I_H$)
- The radiation that reaches the earth surface after scattering in the atmosphere and has lost its directional characteristics is called diffused solar radiation.
- There is some part of the radiation which is reflected back from the objects on the earth surface and reaches other surfaces on the earth. This is called reflected solar radiation.
- Diffused Solar radiation received on a unit horizontal area is the diffused solar radiation (D) and is the sum of direct solar radiation, diffused solar radiation and the reflected solar radiation.
- Global Solar radiation is the quantity of total solar radiation received on a unit horizontal surface (G)

As the Solar Collectors in a Solar Water Heating system are rarely installed in horizontal condition the actual radiation received on an inclined surface becomes important to us. For this purpose, other factors called as **Global Radiation Tilt factors** are used.

When the Solar Collectors are mounted exactly facing SOUTH these are provided in the form of a surface tilt factor based on angle of tilt with respect to the latitude of the place.

When the Solar Collectors are mounted exactly not facing SOUTH an additional correction in the form of factors corresponding to Azimuth Angle need to be applied.

The data for solar radiation at various places in India is available in the following two publications

1) **Hand book of Solar Radiation Data for India 1980** By A Mani

This book provides the information on solar radiation at following places on hourly basis on monthly averages. The data is also available for the hourly air temperature, humidity and wind velocity. The hourly tilt factors for radiation are also available. The azimuth correction factors are available only on annual average basis.

| | | |
|---|---|---|
| 1. Ahmedabad | 7. Jodhpur | 13. New Delhi |
| 2. Bengaluru | 8. Kodaikanal | 14. Pune |
| 3. Bhavnagar | 9. Chennai | 15. Port Blair |
| 4. Mumbai | 10. Mangalore | 16. Shillong |
| 5. Kolkata | 11. Nagpur | 17. Trivandrum |
| 6. Goa | 12. Nandi Hills | 18. Vishakapatnam |

All the data is on average basis. The actual parameter at any point of time is likely to vary in a reasonable range. However for predicting the performance of a solar water heating system no better information is available.

2) **Solar Radiation Over India** By Anna Mani & S Rangarajan

This book has estimated data for 145 places in the country and provides solar radiation and other data on day average basis and other information, on air temperature, humidity, wind speed, in lesser detail.





# Solar Flat Plate Collector performance Test Curves and equations

## OBJECTIVE

The Objective of this chapter is to show the application of collector testing for determining thermal performance of collectors. The test curves and incident angle modifier results will be subsequently used for designing of the systems.

## INTRODUCTION

The testing of solar plate collectors is being done by laboratories and test centers set up by MNRE at various places in the country and testing is being carried out according to IS:12933 (part 5). These tests are used as type tests for determining the suitability of a particular collector being manufactured by a manufacturer for BIS Marking

**The following Tests are carried out on Glazed Solar Flat Plate Collectors:**

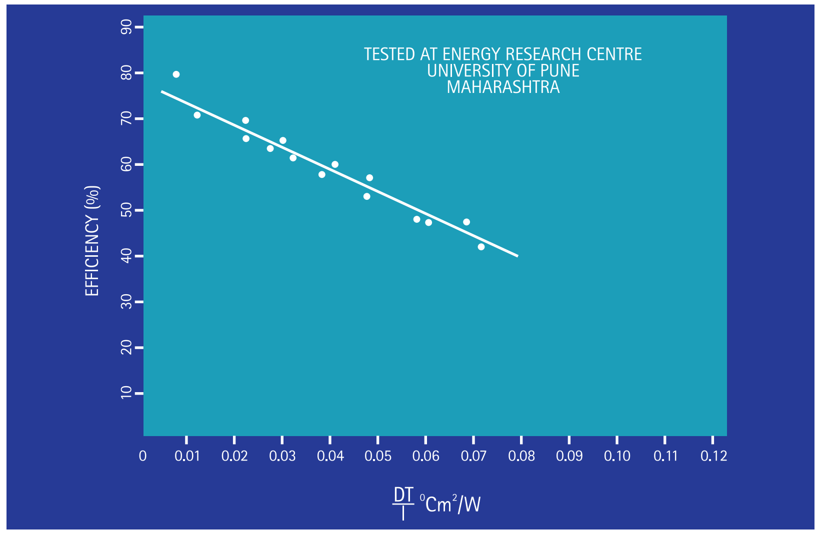
1. Outdoor no flow exposure test
2. Static pressure leakage test
3. Thermal efficiency test
4. Time constant test
5. Incident angle modifier test
6. External thermal shock test
7. Internal thermal shock test
8. Rain penetration test
9. Impact resistance test
10. Transmittance test on cover plate

The purpose of the tests 1,2 6,7,8,9 and 10 is to determine the suitability of using the collector in the environment which it is likely to be subjected to during its use.

The test under 3 that is the thermal performance test is carried out to determine the thermal performance of the solar flat plate collector under specified test conditions and provides a quantitative estimate of the solar collector performance under varying solar incidence and temperature conditions of solar irradiance normal to the collector, surrounding air temperature and inlet water temperature.

The estimated Time Constant in test under 2 helps in estimating the time required to for collector to achieve study state condition before it is fully operational.

The Incident angle modifier test is done to determine the collector efficiency in actual working condition when the radiation will not be normal to collector plane.




Typical Thermal Efficiency Curve for a Flat Plate Collector

The efficiency of a flat plate solar collector is defined as the ratio of rate of the thermal energy delivered to the water to the rate at which solar energy is incident on the collector. It can be calculated from the following relation, is given by:

$$\eta = \frac{m*cp*\ (To-Ti)}{G*Ac}$$

Where

m = mass flow rate of water in kg/hr

cp= specipic heat of water in watts/oc

In terms of collector parameters, n, can also be written as:



To = Temperature of outlet water from the solar collector

Ti = Temperature of inlet water to collector

n = Efficiency of the Solar Collector under test condition

G= Global Solar radiation on collector plan in watts/Sq meter

Ac = Area of collector in Sq meter

The efficiency of a flat plate solar collector is defined as

$$\eta = F_R(\tau \alpha)_c - F_R U_L [\ (T_i - T_a)\ /G]$$

Where $F_R(\tau \alpha)_n$ and $F_{R\,L}$ are the two parameters which characterize the collector under test. These two collector parameters are determined in test 3

Incident Angle Modifier is given by

$$Kv = F_R(\tau \alpha)_c / \ (F_R(\tau \alpha)_n$$

For flat plate collectors whose radiation properties are symmetrical with respect to angle of incidence the variation of $K_v$ with incident angle can be given as

Kv =      $Kv = kv = 1 - bo\left(\frac{1}{\cos\theta} - 1\right)$

In the equation above the symbols used are

$\eta$ = Collector efficiency based on gross collector area, percent

$F_R$ = Solar collector heat removal factor, dimensionless

T =transmittance of the solar flat plate collector cover plate

$(\tau\alpha)_c$ = represents property of cover absorber system taking into account the absorptance of the absorber, transmittance of the cover and multiple reflections between two, dimensionless

$U_L$ = solar collector overall loss coefficient, W/(m2 0C)

Ti = temperature of heat transfer fluid entering the solar collector

Ta = ambient air temperature, 0 C

$(\tau\alpha)$c,n= represents the absorptance transmittance product at normal incidence

Kv = Incident angle modifier, dimensionless

b 0 = Constant used in incident angle modifier equation , dimensionless

$\theta$= angle of incidence between the direct solar rays and the normal to the collector

# Ambient conditions and their effect on solar collector performance

**Introduction**

The output from solar collectors is dependent on the radiation received by the solar collector and the ambient condition. As these conditions are different from place to place the output of a solar collector also varies accordingly. The solar system design and installation is to be done taking into account these conditions.

**Objective**

The purpose of this chapter is to bring out the various factors which affect the performance of the solar collector and how these conditions are different from the conditions under which collector performance test are conducted.

The solar collector performance observed in the test is under outdoor laboratory conditions and performance of the solar collector will be different from these conditions due to following factors:

1. The incident angle of the solar radiation will be far from normal most of the time which affects the performance due to decrease in transmission through glazing. The transmission through glass is maximum when the inclination of radiation is normal to the glass surface and it decreases as the angle of incidence moves away from the normal to the glass surface
2. Shadowing effect of the sides of the collector box at angles other than normal. The sides of the collector box do not affect the radiation which is normal to glass surface. But the radiation which is not normal to the glass surface gets interrupted by the sides of the collector box. The output from such radiation is correspondingly less.
3. The temperature variation in the ambient air which is generally low in morning. The losses from the solar collector are dependent on the temperature difference between the absorber surface and the ambient air. Higher is this difference higher are the losses. This means that net output from the collector will be less if temperature difference is high



4. The dust deposit on the glass between cleaning periods. The dust deposit on the surface of the glass reduces the radiation reaching the absorber plate and reduces the output from the solar collector.
5. Variation in solar incident radiation which are quite low in morning and evening
6. Flow velocity of fluid is likely to be different in actual condition of use. The collector testing is done under standard flow conditions. However in design of the solar system same standard condition cannot be maintained. The higher velocity of flow increases the heat transfer coefficient between the riser tube and water and improves performance, while lower velocity of flow tends to decrease heat transfer and performance.
7. Wind velocity over glass surface may be lower or higher than in test conditions. The higher wind velocity over glass surface has a role in increasing the heat loss from the glass surface.

The conditions under 1, 2, 3 and 5 are covered by the performance test on collectors and the effect these on output from the solar collector can be estimated with reasonable degree of accuracy as explained in the estimation of collector performance infield conditions.

The effect of condition under 4 depends on environmental conditions at the place of collector installation and the frequency and effectiveness of cleaning of the top glazing surface.

The effect of condition 6 depends on the design fluid velocity chosen for the system and has some effect on system performance which has been discussed in the chapter on flow requirements of collector arrays.

The effect of condition 7 varies from place to place and time to time and will be difficult to determine except for general effect of loss increasing marginally with higher wind velocity.

# Collector orientation and its effect on solar collector performance

**Introduction**

The orientation of the solar collector affects the amount of radiation received by the solar collector absorber surface during the day. The design of the solar system is to be done to ensure that maximum radiation is received by the collector during the day.

**Objective**

The purpose of this chapter is to explain how the collector orientation is affecting the performance of the solar water heating system and also to avoid formation of shadows of the collector surface.

The best performance of the collector is observed when the solar radiation is falling on the surface of the glazing of the collector in normal conditions. However with collector orientation being fixed most of the time the solar collector will not receive normal radiation.

The radiation on the tilted surface varies with different seasons as the direction of the solar radiation is inclined less with the normal to horizontal surface in summer and it is inclined more in winter period.

Quite often the requirement of output from the collector is more in winter months than in summer period. This requires an adjustment in the tilt angle of the collector to suit winter conditions An inclination of collector at Lat+15 deg from the horizontal plane and facing south is preferred in this case

However in some cases the requirement of output from collector may be more during summer months and the orientation may be made suitable for summer period. An inclination of collector at Lat-15 deg facing south is preferred for such cases.

When all the year round output from the collectors is optimized the collector tilt may be between these figures. That is an inclination of the collector facing south at Latitude is preferred.

All the time the preferred orientation of the collector is facing south. However in some cases it may not be feasible and a variation of +- 15 deg to the east or west is considered acceptable without significant loss in performance.

**Shadows on the collectors**



The shadow of surrounding structures or the other collectors play an important role in reducing the output from the solar collectors.

The method of determining the distance between collector rows when collectors are placed due south is indicated in the attached figure.

The shadows from other structures around the collector field can be calculated using the sun path diagrams given for different latitudes in the Book on solar radiation over India by Anna Mani and S Rangarajan.

The diagrams give the Azimuth angle, and elevation angle of the sun with reference to time at different months in the year. The length of the shadow of an object can be calculated by using the height of the object and elevation of the sun by the following.

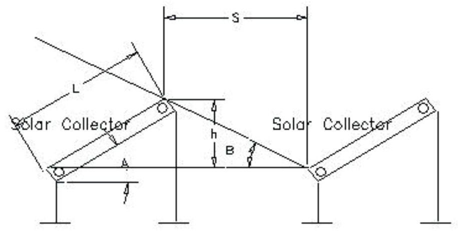
The length of the shadow S is defined as

S = h/ Tan B

Where h = height of the object and B is the angle of elevation of the sun as given in the sun path diagram corresponding to the latitude of the place. The shadow will be inclined to the east west axis as given by the Azimuth angle of the sun. Due to this inclination the shadow may or may not fall on the solar collector at different time of the day.

It may be difficult to avoid shadows from objects in east and west of the collector field during early morning and late evening hours of the day as the sun elevation is low. However at these times the radiation itself is low and also it is inclined to the solar collectors placed facing south. Due to this reason the effect of the early morning and late afternoon shadows is limited on the collector performance and may be ignored.

For solar water heating systems designed for winter applications it may be sufficient to look for shadows in the period 3 hours on either side of solar noon during winter months. During the other period the loss due to shadows may not be significant.




h = Lx Sin A

B =90-Lattitude-23.5

S = h/ Tan B

Figure for determining the distance between rows of collectors placed facing due south.

# Obtaining information from users regarding the application for design of systems

**OBJECTIVE**

The objective of this chapter is to provide guidance on how to seek information from the user so that a selection of the existing systems or design of a new system can be made according to requirement of the user.

**INTRODUCTION**

Before a solar water heating system can be designed there has to be an exchange of information between the potential user and the system designer / installer so that the system can be made suitable for the requirement envisaged by the user. In quite a large no of cases the user may be offered one of the standard products being manufactured but even in such a case the information obtained from the users for selection of the product for his specific use.

Information to be obtained from the user

**User Type / Application :**

**A)** Solar Water Heating Systems required for bathing, cleaning purposes in house hold applications

1. No of users

2. No of Bathrooms

3. Kitchen use

4. Type of usage whether shower, bath tubs, or bathing with bucket of hot water with containers for pouring water

5. Type of Water used - River water , ground water if ground water what are the dissolved solid contents, is the water scale forming or is it with chlorides or fluorides.

6. Cold water storage and supply system whether gravity fed or pressurized water supply is being used.



7. Current usage of water whether any estimate of hot water can be made from electricity or fuel consumption.

8. Shadow free area available for installation of the solar water heating system

Based on the information received an estimate of quantity of hot water required is to be made and a system suitable for that application can be offered.

**B)** Solar water heating system required for bathing cleaning purposes in institution or commercial establishments such as hostels, hospitals, hotels, restaurants and religious or social groups with residential accommodations

The requirement is to be assessed from the user with the help of user pattern, existing use or use in similar set up in nearby area. Other questions need to be asked as in case of house hold applications to determine that the assessment is neither too large nor too small as compared to normal usage by similar groups.

The assessment of the quality of water and pressure is to be made for determining the requirement of the type of system. Calculation of area required for Collector installation for this quantity of hot water is to be done. After this the area availability is to be confirmed with the site survey.

The back-up system requirement is to be assessed based on existing system of heating water or based on electricity / fuel available in the area and convenience of using the back -up system for cloudy days.

If the area for installation of Collectors is not sufficient to meet the entire requirement of the Hot water, then the system has to be provided to ensure maximum benefit and ease of switch over between the existing water heating system and solar water heating system. Depending upon the area available for the installation of Collectors, calculations have to be done to arrive at the percentage / proportion / part of the demand that can be met. The user must be informed of this accordingly.

The layout and quantity of hot water distribution pipe lines need to be worked out and assessed. The availability of the cold water should be enquired from the user. The suitability of the available cold water for the solar water heating system should be ascertained.

If a hot water supply system already exists in an establishment, the method of integrating the solar water heating system with that existing hot water system is to be discussed with the user.

**C)** Requirement of Solar Water Heating system in Industry for various purposes

1. Hot water has been in use in dairy industry

2. Leather industry uses hot water in leather processing.

3. Paper and pulp industry uses hot water for processes.

4. Hot water is used in textile processing

5. Sheet metal processing industry uses hot water for degreasing applications and phosphating and electroplating baths are also required to be maintained at high temperature as per process parameters.

6. Hot water requirement as feed water to the boilers

In some of the applications in the Industry the Hot water is used for transfer of heat for use in the process. In such applications, the heat transferred from hot water is used for temperature maintenance requirements in the processes. Water is only the medium of supplying such heat and quantum of heat required at the temperature of requirement is to be assessed and system should be designed according to that requirement.

Whereas, in some of the applications in the Industry the hot water is consumed in the process. In all such applications the assessment is to be made of the quantity of hot water use, temperature requirement, pressure requirement and other operational limitations.

**D)** Swimming pools Heating Systems : Water is required to be maintained at comfortable temperatures and solar water heating systems can be used for this purpose.





# Estimating the performance of Solar Collector in field conditions

## INTRODUCTION

The Thermal Efficiency Test is carried out under specified test conditions to determine the thermal performance of the Solar Flat Plate Collectors. This provides a quantitative estimate of the Solar Collector performance under varying solar incidence and temperature conditions.

But the test conditions are different from the adverse & varying Environmental conditions in which the Solar Flat Plate Collectors will be operating. Hence, a fair estimate of the expected performance of Solar Flat Plate Collectors in those conditions is required. This fair estimate will help in arriving at solar collector area required to operate in the given conditions.

## OBJECTIVE

The objective of this chapter is to suggest ways of making an estimate of thermal performance of the selected Solar Flat Plate Collectors by using the solar radiation data for the place where such collectors are being installed. The solar collector performance is to be calculated based on the conditions in which the solar collector will be installed. The estimation is to be related to performance test report and environmental factors.

The starting point of the estimation is the solar collector thermal performance test report and the following parameters from the test report

The solar collector performance is to be calculated based on the conditions in which the solar collector will be installed.

$n_o$ = FR( $\tau\alpha$ ),n ( This is given in the collector test report)

$F_r U_L$ = Slope of the efficiency curve (This is given in the collector test report)

Ti = inlet temperature of fluid in the solar collector

Ta = Ambient air temperature

$b_o$ = Constant used in incident angle modifier ( This is given in the collector test report)

We shall calculate the angle $\theta$ , which is the angle of incidence between the direct solar rays and the normal to the collector at different times of the day and during different months of the year. This will be used to obtain the values of $K_V$ incident angle modifier.

Using the radiation data and tilt factor data, we shall also calculate G, the solar radiation falling on the collector plane at different times in the day and for different months.

All these calculations are illustrated in the form an excel worksheet. This will facilitate substituting the numbers relevant to the designer for their applications.

Formula for calculating $\theta$ for a solar collector with a tilt is shown below ( $\theta$ is the angle which the normal to the plane makes with the radiation beam received from the sun)

$$\text{Cosine}\ \theta = \text{Sine}\ \varphi\ (\text{Sine}\ \delta . \text{Cos}\ \beta + \text{Cos}\ \delta . \text{Cos}\ \gamma . \text{Cos}\ \omega . \text{Sine}\ \beta) + \text{Cos}\ \varphi\ (\text{Cos}\ \delta . \text{Cos}\ \omega . \text{Cos}\ \beta - \text{Sine}\ \delta . \text{Cos}\ \gamma . \text{Sine}\ \beta) + \text{cos}\ \delta . \text{Sine}\ \gamma . \text{Sine}\ \beta . \text{Sine}\ \omega$$

Where $\delta$ ( in degrees) = 23.45 sin [ (284+n) 360/365 ]

The declination angle is the angle of the line joining the centre of the earth and the sun with its projection on equatorial plane.

$\Phi$ is the latitude angle of the place

$\beta$ is the angle of inclination of the collector plane with the horizontal

$\omega$ is the hour angle (It is taken as zero at solar noon time and changes by 15 degree for every hour from solar noon. The value is positive for period after solar noon and negative for period before solar noon)

n is the no of the day from beginning of the year

$\theta$ zis the zenith angle of the sun which the beam of radiation makes with the vertical to the earth at that place i.e. when

$\beta$=0

The beam radiation reaching the earth on horizontal plane or when $\beta$ =0 is available from the book on solar radiation.

The beam radiation on an inclined plane is calculated from the equation

Ip b= Ib $\theta$ /cos $\theta$ zIpd=0.5 Id(1+Cos $\beta$ )



(Ipb = Ip Cos $\theta$ /Cos $\theta$ z)

Ib = Direct solar radiation in horizontal surface

Id = Diffused solar radiation in horizontal surface

Ipb = Direct solar radiation in collector plane

Ipd = Diffused solar radiation in collector plane

Ipd = 0.5$I_d$(1+Cos $\beta$ )

Effective radiation on the collector plane is determined by using the using the incident angle modifier from the collector test for beam radiation

Effective radiation on collector plane I

=$I_{pb}$(1-b0(1/cos $\theta$ -1)

At the time of testing only the global solar radiation on the collector plane is measured. No adjustment is done for the ratio of diffused and direct solar radiation. During the field conditions the ratio of diffused radiation and the direct solar radiation also does not get adjusted automatically for light transmission, this may affect the performance. This part is not being taken care of in the methods for calculations used.

For the purpose of efficiency calculation in forced flow systems, where the flow rate is high the $T_i$ be considered as the average of the inlet temperature to the system and the outlet temperature from the system. $T_o$ is the outlet temperature from the system.

In case of thermo-siphon systems the inlet temperature remains very near to the cold water temperature but outlet temperature is very high. It is reasonable to assume that $T_i$ is equivalent to average temperature in the Collector. Some correction needs to be applied for reduction in heat removal factor ($F_r$) due to decreased heat transfer coefficient in the tubes because of low velocity of flow. A 5% correction may be used for approximate working of the output from the solar collectors. This however is an estimate.

# Table 1

| Calculation of Solar radiation at Incline plane and collector output at Delhi | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Month | Jan | n | | | | | | | | | | |
| | δ | -21.3 | 15 | | γ deg | 0 | | φ | 28.58 | β deg | 43 | bo | 0.1 |
| | | | | | | | | | | | | | |
| | δ rad | -0.37 | | | γ rad | 0 | | φ rad | 0.50 | β rad | 0.75 | Fr τα | 0.65 |
| | | | | | | | | | | | | | |
| | Cold | 15 | | To | 60 | | Ti | 37.5 | | | | | |
| | input | | | | | | | | | | | | |
| | A | 2 | | U | Fr ι | 4 | Watt/sq meter | | | | | | |
| | | | | | | | | | | | | | |
| LAT | G | Gm | Gm | ω | ω | Cosθ | Cosθz | Rb | Rd | Rbe | I | Ta | Qu |
| ending | global | Direct | diffuse | deg | rad | | | | | | | | |
| | | | | | | | | | | | | | |
| 6 | 0 | 0 | 0 | -97.5 | -1.702 | -0.03 | -0.28 | 0 | 0 | 0 | 0 | 8.90 | |
| | | | | | | | | | | | | | |
| 7 | 4 | 1 | 3 | -82.5 | -1.440 | 0.21 | -0.07 | -3 | 3 | -2 | 1 | 8.60 | |
| | | | | | | | | | | | | | |
| 8 | 96 | 45 | 51 | -67.5 | -1.178 | 0.44 | 0.14 | 140 | 44 | 122 | 166 | 8.70 | |
| | | | | | | | | | | | | | |
| 9 | 271 | 168 | 103 | -52.5 | -0.916 | 0.64 | 0.32 | 331 | 89 | 312 | 402 | 11.00 | 310 |
| | | | | | | | | | | | | | |
| 10 | 433 | 293 | 140 | -37.5 | -0.655 | 0.81 | 0.48 | 497 | 121 | 485 | 606 | 13.80 | 598 |
| | | | | | | | | | | | | | |
| 11 | 556 | 396 | 160 | -22.5 | -0.393 | 0.92 | 0.58 | 628 | 139 | 623 | 762 | 16.30 | 821 |
| | | | | | | | | | | | | | |
| 12 | 618 | 444 | 174 | -7.5 | -0.131 | 0.99 | 0.64 | 686 | 151 | 685 | 835 | 17.00 | 922 |
| | | | | | | | | | | | | | |
| 13 | 615 | 443 | 172 | 7.5 | 0.131 | 0.99 | 0.64 | 684 | 149 | 683 | 832 | 17.80 | 924 |
| | | | | | | | | | | | | | |
| 14 | 552 | 390 | 162 | 22.5 | 0.393 | 0.92 | 0.58 | 619 | 140 | 614 | 754 | 19.60 | 837 |
| | | | | | | | | | | | | | |
| 15 | 430 | 293 | 137 | 37.5 | 0.655 | 0.81 | 0.48 | 497 | 119 | 485 | 603 | 19.70 | 642 |
| | | | | | | | | | | | | | |
| 16 | 268 | 168 | 100 | 52.5 | 0.916 | 0.64 | 0.32 | 331 | 87 | 312 | 399 | 19.60 | 376 |
| | | | | | | | | | | | | | |
| 17 | 99 | 48 | 51 | 67.5 | 1.178 | 0.44 | 0.14 | 150 | 44 | 130 | 175 | 19.10 | 80 |
| | | | | | | | | | | | | | |
| 18 | 5 | 2 | 3 | 82.5 | 1.440 | 0.21 | -0.07 | -6 | 3 | -4 | 0 | 17.20 | |
| | | | | | | | | | | | | | |
| 19 | 0 | 0 | 0 | 97.5 | 1.702 | -0.03 | -0.28 | 0 | 0 | 0 | 0 | 15.50 | |
| | | | | | | | | | | | | | |
| Total | 3947 | 2691 | 1256 | | | | | 4553 | 1087 | | | | 5509 |





# Various Solar Collector layouts and effect of these on other parameters of solar water heating system

## Introduction

Any large solar water heating system has a large number of solar collectors installed. The solar collectors may be arranged in different ways for the passage of heating fluid or water. Different flow arrangements have been used for different systems.

## Objective

The objective of discussing this topic is to familarize the designers and installers of the solar water heating systems with the arrangements. Various aspects, of these collector arrangements with reference to system performance, are explained here

In general, the following different types of arrangements of connecting Solar collectors are in practice :

1. All Parallel arrangement
2. All Series Arrangement
3. Combination of Parallel and Series arrangement

1. All parallel arrangement –

In this arrangement, all the collectors receive the input water at the bottom header from the same source and deliver hot water from the top header to a common outlet. The collectors may be connected by connecting the bottom and top headers directly. In such systems, the input water is received by the first collector and then is passed on to other collectors through header to header connections. Wherever, due to space or other constraints the header to header connections are not possible, such connections could be made through pipe arrangements.

The systems with this type of arrangement have very low pressure drops. Water flow can be managed with a suitable design in a thermo syphon system and may be ensured in a forced flow system with a pump with very low pressure head and high flow rate.

The number of solar collectors connected in parallel with direct connections from one collector header to the other is limited to a maximum of 5 or 6 to obtain a good flow distribution. When the number of collectors in a system is more than six, then we will have to design a piping grid like arrangement to ensure equal flow in all collectors.

a) Thermo Siphon Systems: All Parallel arrangement is invariably used in all thermo-siphon systems where the available head for flow is of the order of few millimetres of water column. The alternative arrangements have significantly higher pressure requirement which is not generated by thermo-siphon solar water heating systems. However, there are some exceptions to this rule as in the case of systems with collectors placed on a sloping roof.

b) Forced Flow Systems: With all parallel arrangement in case of forced flow systems the flow rate requirement being high (The flow requirements are high to achieve good heat transfer in the solar collectors), the temperature rise in one pass does not reach the useful temperature in water or heating fluid. It must be circulated a number of times through the collector arrays to achieve the desired temperature. The piping size increases due to high flow rate. Pumps used have a high flow rate with low static head which are readily available in the market. The piping system needs to be designed carefully to ensure a reasonable distribution of flow in all the collectors.

2. All series arrangement –

In this arrangement, the output from the first collector is fed to the inlet of the next collector and so on till the last collector. The high flow rate through the collectors is maintained and required temperature may be achieved in one pass. Normally available pumps with moderately high flow rates at sufficient head are suitable for these systems. The high flow rate through the collectors ensures better heat transfer.

There is, however, a limitation on the number of collectors which can be connected in series. This limitation arises from two factors namely, the pressure drop in the flow and phase separation (separation of dissolved air from water) during the heating process.

**Pressure drop:** The pressure drop increases due to change in flow directions, the number of connecting paths and high flow rate needed for maintaining the required temperature.

**Phase separation:** Water at low temperatures has very high volumes of dissolved air in it. The solubility of air in water decreases at higher temperatures, which means that air gets separated from water as the water temperature is increased. This phase separation results in combined flow of released air and water in the same passages. This two phase flow of both released / separated air and water creates problems. The released air does not move with water in the downward direction due to buoyancy effect and hence it restrains the normal movement of the water in zigzag path.



Practically a system with up to 11 (Eleven) collectors in series has been found to be feasible. Problems have been encountered with higher number of collectors in series.

3. Combination of series and Parallel arrangements –

For higher capacity systems where a large number of collectors are to be connected only all Parallel and only all series arrangement is not possible without disadvantages and limitations. Hence, a combination of series and parallel arrangements could be designed to take advantages of both arrangements while avoiding the limitations of the respective systems.

In this type of arrangement first, some of the collectors may be grouped in series and then each series group is connected in parallel. Similarly, secondly some of the collectors may be grouped in parallel and then each parallel group is connected in series. Effectively, there is not much difference in the output from either of the two combinations and only the site limitations is the governing factor while deciding upon the configuration chosen. For example, if all the collectors in a system are to be installed on a flat surface then it would be possible to have either of the combinations. However, if the collectors have to be installed at different terrace levels, then the collectors at each terrace level may be connected in parallel and then these parallel groups may be connected in series with the other groups at other levels.

# Different operating requirements for Solar water heating applications

**Introduction**

The solar water heating systems are being used for different purposes and differently by different users for the same purpose also. The attempt of any system designer has to be to satisfy the users requirement.

**Objective**

The objective of this chapter is to enumerate how the requirements for users differ and how we can account for these in the design and installation.

Before the design of the Solar Water Heating system is taken up we have to understand the specific requirement of the end user or the application from the system. Such operating requirements of the most general applications are being enlisted below for ready reference

1. <u>SWH for bathing and cleaning application:</u> The simplest solar water heating systems which have been installed in large numbers are the solar water heating systems used for bathing and cleaning in domestic or commercial / institutional sector. Some of the operating requirements and design considerations are

a) Such systems have the final goal of providing hot water at the tap or shower i.e., the end use point in the temperature range of 35 to 45° C. The water at higher temperature may have to be mixed with cold water before use.

b) The requirement of such hot water could be there at any time of the day but is predominantly during morning or evening hours.

c) This implies that the hot water is less likely to be used when heating is taking place during sunshine hours.

d) That determines that the solar water heating system will generally need to have a storage facility equivalent to the total demand to meet the requirement.

e) The storage facility should be suitable to keep the water hot for 12-18 hours before use.

f) The storage must be such as to retain heat without significant loss during night hours when the temperature is likely to be low.



g) A mechanism of transfer of heat or hot water from the solar collector to the storage tank is required.

h) That mechanism should be such that it shall work only when the heat is being delivered from the solar collectors to storage and it should stop when heat is not being delivered to the storage.

i) The water from the storage is to be delivered to end use point without significant loss of temperature.

j) The hot water being used from the storage need to be replaced with cold water which can be heated further.

k) The overall arrangement of the system should be such that flow of water from cold water storage to hot water tank is feasible.

l) In the process of delivering cold water to hot water tank, there should not be significant drop in the temperature of the stored water.

m) There may not be any heating or insufficient heating from solar system on some days due to clouds or rain.

n) A back up device is required to provide hot water or to boost the temperature of the water.

o) The backup device should work only when required otherwise it may consume energy.

p) Above all in meeting all these requirements the components of the solar water heating system should be compatible with the quality of water being used and must be able to last for a long time in outdoor environment.

q) The design and installation of solar water heating system must ensure integration with the existing conventional water heating systems. These systems are retained as back-up systems or when the solar water heating systems are used for partially meeting the requirements.

All these operating requirements are to be considered by the designer of such a system so as to make it a successful system. The installers of the systems have to ensure that there are no flaws are left in the system as to impede its use in any way.

2. <u>SWH for Laundry & Kitchen cleaning application:</u> The operating requirements and the design considerations are mostly similar to the above mentioned in SWH for Bathing

& Cleaning application.

a) Such systems have the final goal of providing hot water at the end use point as per the specific requirement of the equipment installed. The temperature range should be ascertained from the user. The water at higher temperature may have to be mixed with cold water before use.

b) The requirement of such hot water could be there at specific hours of the day and should be ascertained from the user.

3. SWH for Swimming Pools application:

Another application of Solar Water Heating system which is quite close to the Bathing application is in the swimming pool heating system. The application is similar to bathing application but for a designer and installer of the solar water heating system it is an entirely different application. These heating systems are designed to extend the use of the swimming pools to periods when water in the swimming pools becomes too cold for use.

a) The water under use is not being consumed but is retained in the swimming pool.

b) There is practically very little of fresh water which is being added to the swimming pool.

c) There is a system of filtration and chemical dosing of the swimming pool water.

d) The volume of water is very large.

e) The swimming pools are being used with long contact with human body and with some physical activity so temperature in the range of 25 to 30$^{0}$ C is considered desirable.

f) The storage of heat is in the pool and no extra storage is required.

g) The heat is to be retained during the period when the pool is not in use.

h) The solar water heating system is required for making up the loss of heat when the pool is in use and loss of heat when the pool is not in use.

i) The swimming pools may be indoor or outdoor type (with or without roofing and enclosures).

j) There are some swimming pools which are being used in the hospitals for hydro-therapy and are used in temperature range of 33 to 38$^{0}$ C.



k) During the non use period pool may require a cover to suppress the losses due to evaporation.

4. SWH for Industrial Bath application: An application of solar water heating which is quite similar with Swimming Pools application is the heating of industrial bath heating systems.

a) The water under use is not being consumed but is retained in the industrial bath.

b) There is practically very little of fresh water which is being added to the industrial bath.

c) There will be corrosive elements in the Industrial Bath and indirect heating system may be invariably required.

d) The volume of water may be very large.

e) The storage of heat is in Industrial Bath and marginal storage may be required to balance the Solar heat availability and the demand of heat for maintaining the temperature.

f) The heat is to be retained during the period when the Bath is not in use.

g) The back up heating system is required for making up the loss of heat when the solar heat is not available.

h) These systems do not consume major portion of the water or fluids in use and the requirement is for maintaining the temperature of the bath in the required temperature range.

i) The chemical concentration may be very high or at times negligible as in rinsing baths. The temperature requirements are quite different and most of the time much higher than for a swimming pool.

5. An application of solar water heating system which has been used to some extent is in the industry is for providing hot water for cleaning in dairy industry, for processing of leather ,for processing of textiles and in food processing industry. These applications require hot water in large quantities and consume quite a lot of fuel which can be economically replaced by solar water heating systems. The requirement is such applications is generally at higher temperatures but can be met from solar systems.

# Determining flow requirements of collector arrays under operating conditions

**Introduction**

The solar water heating systems are designed to provide hot water as per the requirements of specific use. The hot water is generated when the water flows through the solar collector. The functioning of the solar collector is dependent on the flow of water or heating fluid through the solar collector.

**Objective**

The objective of this chapter is to explain the method for determining the required rate of flow through the collectors. This information will be subsequently used for determining the specification of the components which have a role to play in ensuring the flow rate.

After calculating the heat output required from the solar collectors, we can calculate the number of solar collectors required for the application under field conditions. These collectors are to be arranged in the available space so that the shadow of external elements and the other part of the solar system does not fall on the other collectors.

The flow rate of water through the collector arrays is determined from the three requirements.

**1)** The temperature rise of water desired in single pass

**2)** A high flow rate required for better heat removal factor and higher collector efficiency

**3)** A low flow rate to be maintained for reducing parasitic power used in pumping of water

The requirement under 2 and 3 are conflicting and an optimization is required.

Calculating flow rate from temperature rise

$Q = M\,C_p(T_o - T_i)$



$Q = A\,N\,\eta\,I$

Where

M= Hourly mass flow rate through the collectors

Cp= Specific heat of water or fluid

To= Outlet temperature of fluid desired.

Ti = Inlet temperature of water

Q= the amount of heat delivered per hour from the collectors

A= Area of the collector

N= Number of collectors in the solar system

$\eta$ = Efficiency of the solar collector system under operating conditions

I= Effective solar radiation on the collector per hour/per square meter of collector area

The flow through individual collector in all parallel arrangement is

M/m

If a series of n number collectors is used

M = m

The units need to be balanced as conversion from KWh to Kcal may be required.

As solar radiation on the collector plane is varying all the time the flow rate, in case of forced flow systems, may be the maximum flow rate required as per the radiation data. A control mechanism is needed to have lesser flows or interrupted flows in case of forced flow systems.

In case of thermo-siphon systems there is no control over the flows but it has a natural control on flows which shall be discussed later.

# Estimation of pressure drop in collector arrays under required flow conditions

**Introduction**

The calculations of pressure drop through the solar collector arrays help us in arranging the collectors in optimum arrangement. The pressure drop calculations will also be used in determining optimum pipe size and whether any pump is required.

**Objective**

The objective of this chapter it to provide designers with method of calculating the pressure drop in passage of water through the collectors. These calculations are then used to determine the optimum pipe sizes and also to select the pump required

The pressure loss in the process of flow of water through collectors can be considered as the sum of pressure loss

**a)** Due to friction loss inflow of water through headers

**b)** Due to friction loss in flow through the risers

**c)** Loss of velocity head due to change in direction at the entry and exit of headers

**d)** Loss of velocity head in change of direction of flow from headers to risers and risers to headers.

The friction loss is determined by using the friction coefficient as for smooth pipes

Friction factor f=0.316 /Re0.25 for turbulent /transient flows with Re>2000

Friction factor f=64/Re for streamline flows with Re < 2000

Re = Reynold`s number for the flow as given by

$Re = U_m d/\mathbf{v}$

Where um is the mean velocity in meter/sec through a pipe

D is the diameter of pipe in meter

**v** is the kinematic viscosity of the liquid at the condition in meter$^2$/second

Velocity head is given by $U_m^2/2g$ where g= acceleration due to gravity



# Table 2

| Calculation of Pressure Drop Through Single Collector | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Collector Size | | Height | 2.08 | Width | 1.07 | Projection | 0.045 | No. of Collectors | | 1 |
| Header | Length | 1.16 | Diameter | 0.0254 | Thickness | 0.00071 | ID | 0.02398 | | |
| Riser | Length | 1.9702 | Diameter | 0.0125 | Thickness | 0.0005 | ID | 0.0115 | Number | 9 |
| | Riser Projection in Header | | | 0.002 | | | | | | |
| Flow Rate | | Temp | viscosity | Velocity | Re | f | f loss | v loss | (f+v) | Total |
| Litre/hr | | Deg C | m sq/Sec | m/sec | | | mm water | mm water | | |
| 10 | Header B | 20 | 0.00000106 | 0.0037 | 75.900 | 0.843 | 0.028 | 0.001 | 0.029 | |
| | Header T | 60 | 0.00000048 | 0.0037 | 168.314 | 0.380 | 0.013 | 0.001 | 0.013 | |
| | Risers | 40 | 0.00000066 | 0.0030 | 51.854 | 1.234 | 0.095 | 0.000 | 0.096 | 0.137 |
| 20 | Header B | 20 | 0.00000106 | 0.0073 | 151.800 | 0.422 | 0.056 | 0.003 | 0.058 | |
| | Header T | 60 | 0.00000048 | 0.0073 | 336.629 | 0.190 | 0.025 | 0.003 | 0.028 | |
| | Risers | 40 | 0.00000066 | 0.0059 | 103.708 | 0.617 | 0.190 | 0.002 | 0.192 | 0.278 |
| 30 | Header B | 20 | 0.00000106 | 0.0110 | 227.701 | 0.281 | 0.084 | 0.006 | 0.090 | |
| | Header T | 60 | 0.00000048 | 0.0110 | 504.943 | 0.127 | 0.038 | 0.006 | 0.044 | |
| | Risers | 40 | 0.00000066 | 0.0089 | 155.561 | 0.411 | 0.285 | 0.004 | 0.290 | 0.423 |
| 40 | Header B | 20 | 0.00000106 | 0.0146 | 303.601 | 0.211 | 0.111 | 0.011 | 0.122 | |
| | Header T | 60 | 0.00000048 | 0.0146 | 673.257 | 0.095 | 0.050 | 0.011 | 0.061 | |
| | Risers | 40 | 0.00000066 | 0.0119 | 207.415 | 0.309 | 0.381 | 0.007 | 0.388 | 0.571 |
| 50 | Header B | 20 | 0.00000106 | 0.0183 | 379.501 | 0.169 | 0.139 | 0.017 | 0.156 | |
| | Header T | 60 | 0.00000048 | 0.0183 | 841.572 | 0.076 | 0.063 | 0.017 | 0.080 | |
| | Risers | 40 | 0.00000066 | 0.0149 | 259.269 | 0.247 | 0.476 | 0.011 | 0.487 | 0.723 |
| 60 | Header B | 20 | 0.00000106 | 0.0439 | 910.803 | 0.070 | 0.334 | 0.098 | 0.433 | |
| | Header T | 60 | 0.00000048 | 0.0439 | 2019.772 | 0.032 | 0.151 | 0.098 | 0.249 | |
| | Risers | 40 | 0.00000066 | 0.0178 | 311.123 | 0.206 | 0.571 | 0.016 | 0.587 | 1.269 |
| 70 | Header B | 20 | 0.00000106 | 0.0256 | 531.302 | 0.120 | 0.195 | 0.033 | 0.228 | |
| | Header T | 60 | 0.00000048 | 0.0256 | 1178.200 | 0.054 | 0.088 | 0.033 | 0.121 | |
| | Risers | 40 | 0.00000066 | 0.0208 | 362.977 | 0.176 | 0.666 | 0.022 | 0.688 | 1.038 |
| 80 | Header B | 20 | 0.00000106 | 0.0293 | 607.202 | 0.105 | 0.223 | 0.044 | 0.267 | |
| | Header T | 60 | 0.00000048 | 0.0293 | 1346.514 | 0.048 | 0.100 | 0.044 | 0.144 | |
| | Risers | 40 | 0.00000066 | 0.0238 | 414.831 | 0.154 | 0.761 | 0.029 | 0.790 | 1.201 |
| 90 | Header B | 20 | 0.00000106 | 0.0329 | 683.102 | 0.094 | 0.251 | 0.055 | 0.306 | |
| | Header T | 60 | 0.00000048 | 0.0329 | 1514.829 | 0.042 | 0.113 | 0.055 | 0.168 | |
| | Risers | 40 | 0.00000066 | 0.0267 | 466.684 | 0.137 | 0.856 | 0.036 | 0.893 | 1.367 |
| 100 | Header B | 20 | 0.00000106 | 0.0366 | 759.002 | 0.084 | 0.279 | 0.068 | 0.347 | |
| | Header T | 60 | 0.00000048 | 0.0366 | 1683.143 | 0.038 | 0.126 | 0.068 | 0.194 | |
| | Risers | 40 | 0.00000066 | 0.0297 | 518.538 | 0.123 | 0.952 | 0.045 | 0.997 | 1.537 |
| 110 | Header B | 20 | 0.00000106 | 0.0403 | 834.902 | 0.077 | 0.306 | 0.083 | 0.389 | |
| | Header T | 60 | 0.00000048 | 0.0403 | 1851.457 | 0.035 | 0.138 | 0.083 | 0.221 | |
| | Risers | 40 | 0.00000066 | 0.0327 | 570.392 | 0.112 | 1.047 | 0.054 | 1.101 | 1.711 |
| 120 | Header B | 20 | 0.00000106 | 0.0439 | 910.803 | 0.070 | 0.334 | 0.098 | 0.433 | |
| | Header T | 60 | 0.00000048 | 0.0439 | 2019.772 | 0.032 | 0.151 | 0.098 | 0.249 | |
| | Risers | 40 | 0.00000066 | 0.0357 | 622.246 | 0.103 | 1.142 | 0.065 | 1.207 | 1.888 |

# Table 3

| Calculation of Pressure Drop Through Five collectors | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Collectors Size | | Height | 2.08 | Width | 1.07 | Projection | 0.045 | No. of Collectors | | 5 |
| Header | Length | 1.16 | Diameter | 0.0254 | Thickness | 0.00071 | ID | 0.02398 | | |
| Riser | Length | 1.9702 | Diameter | 0.0125 | Thickness | 0.0005 | ID | 0.0115 | Number | 9 |
| | Riser Projection in Header | | | 0.002 | | | | | | |
| Flow Rate | per | Temp | viscosity | Velocity | Re | f | f loss | v loss | (f+v) | Total |
| Litre/hr | collector | Deg C | m sq/Sec | m/sec | | | mm of water | | | |
| 10 | Header B | 20 | 0.000001060 | 0.015376 | 318.838 | 0.200729 | 0.585 | 0.01205 | 0.5971 | |
| | Header T | 60 | 0.000000478 | 0.015376 | 707.047 | 0.090517 | 0.264 | 0.01205 | 0.2759 | |
| | Risers | 40 | 0.000000659 | 0.002971 | 51.854 | 1.234239 | 0.095 | 0.00045 | 0.0956 | 0.969 |
| 20 | Header B | 20 | 0.000001060 | 0.030752 | 637.676 | 0.100364 | 1.170 | 0.04820 | 1.2183 | |
| | Header T | 60 | 0.000000478 | 0.030752 | 1414.093 | 0.045259 | 0.528 | 0.04820 | 0.5758 | |
| | Risers | 40 | 0.000000659 | 0.005943 | 103.708 | 0.617119 | 0.190 | 0.00180 | 0.1921 | 1.986 |
| 30 | Header B | 20 | 0.000001060 | 0.046129 | 956.514 | 0.066910 | 1.755 | 0.10845 | 1.8636 | |
| | Header T | 60 | 0.000000478 | 0.046129 | 2121.140 | 0.120000 | 3.148 | 0.10845 | 3.2562 | |
| | Risers | 40 | 0.000000659 | 0.008914 | 155.561 | 0.411413 | 0.285 | 0.00405 | 0.2895 | 5.409 |
| 40 | Header B | 20 | 0.000001060 | 0.061505 | 1275.352 | 0.050182 | 2.340 | 0.19280 | 2.5330 | |
| | Header T | 60 | 0.000000478 | 0.061505 | 2828.186 | 0.100000 | 4.663 | 0.19280 | 4.8561 | |
| | Risers | 40 | 0.000000659 | 0.011886 | 207.415 | 0.308560 | 0.381 | 0.00720 | 0.3878 | 7.777 |
| 50 | Header B | 20 | 0.000001060 | 0.076881 | 1594.190 | 0.040146 | 2.925 | 0.30126 | 3.2265 | |
| | Header T | 60 | 0.000000478 | 0.076881 | 3535.233 | 0.090000 | 6.558 | 0.30126 | 6.8591 | |
| | Risers | 40 | 0.000000659 | 0.014857 | 259.269 | 0.246848 | 0.476 | 0.01125 | 0.4870 | 10.573 |
| 60 | Header B | 20 | 0.000001060 | 0.092257 | 1913.028 | 0.033455 | 3.510 | 0.43381 | 3.9441 | |
| | Header T | 60 | 0.000000478 | 0.092257 | 4242.280 | 0.089000 | 9.338 | 0.43381 | 9.7721 | |
| | Risers | 40 | 0.000000659 | 0.017829 | 311.123 | 0.205706 | 0.571 | 0.01620 | 0.5872 | 14.303 |
| 70 | Header B | 20 | 0.000001060 | 0.107633 | 2231.866 | 0.120000 | 17.138 | 0.59046 | 17.7282 | |
| | Header T | 60 | 0.000000478 | 0.107633 | | 0.085000 | 12.139 | 0.59046 | 12.7297 | |
| | Risers | 40 | 0.000000659 | 0.020800 | 362.977 | 0.176320 | 0.666 | 0.02205 | 0.6882 | 31.146 |
| 80 | Header B | 20 | 0.000001060 | 0.123009 | 2550.704 | 0.110000 | 20.519 | 0.77122 | 21.2899 | |
| | Header T | 60 | 0.000000478 | 0.123009 | 5656.373 | 0.080000 | 14.923 | 0.77122 | 15.6939 | |
| | Risers | 40 | 0.000000659 | 0.023772 | 414.831 | 0.154280 | 0.761 | 0.02880 | 0.7901 | 37.774 |
| 90 | Header B | 20 | 0.000001060 | 0.138386 | 2869.542 | 0.100000 | 23.608 | 0.97607 | 24.5842 | |
| | Header T | 60 | 0.000000478 | 0.138386 | 6363.419 | 0.075000 | 17.706 | 0.97607 | 18.6822 | |
| | Risers | 40 | 0.000000659 | 0.026743 | 466.684 | 0.137138 | 0.856 | 0.03645 | 0.8929 | 44.159 |
| 100 | Header B | 20 | 0.000001060 | 0.153762 | 3188.380 | 0.100000 | 29.146 | 1.20503 | 30.3509 | |
| | Header T | 60 | 0.000000478 | 0.153762 | 7070.466 | 0.075000 | 21.859 | 1.20503 | 23.0644 | |
| | Risers | 40 | 0.000000659 | 0.029714 | 518.538 | 0.123424 | 0.952 | 0.04500 | 0.9966 | 54.412 |
| 110 | Header B | 20 | 0.000001060 | 0.169138 | 3507.218 | 0.090000 | 31.740 | 1.45809 | 33.1979 | |
| | Header T | 60 | 0.000000478 | 0.169138 | 7777.513 | 0.073000 | 25.745 | 1.45809 | 27.2026 | |
| | Risers | 40 | 0.000000659 | 0.032686 | 570.392 | 0.112204 | 1.047 | 0.05445 | 1.1012 | 61.502 |
| 120 | Header B | 20 | 0.000001060 | 0.184514 | 3826.056 | 0.016727 | 7.020 | 1.73524 | 8.7557 | |
| | Header T | 60 | 0.000000478 | 0.184514 | 8484.559 | 0.007543 | 3.166 | 1.73524 | 4.9011 | |
| | Risers | 40 | 0.000000659 | 0.035657 | 622.246 | 0.102853 | 1.142 | 0.06480 | 1.2067 | 14.864 |





# Estimation of pressure drop in Piping under required flow conditions

**Introduction**

There is Pressure drop in Pipes and a fair estimate of the same has to be arrived at to properly design the Piping System for Solar Water Heating Systems. The pressure drop calculations will be used in determining optimum pipe size and whether any pump is required.

**Objective**

The objective of this chapter it to provide designers with the method of calculating the pressure drop in passage of water through the connecting piping. These calculations are then used to determine the optimum pipe sizes and also to select the pump required

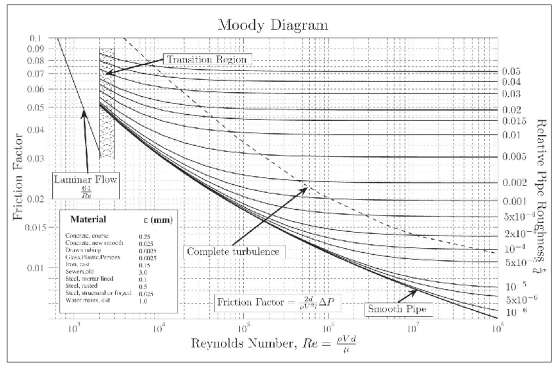
**Pressure Loss in flow through Piping**

In the piping system, the pressure loss can be calculated by taking into account the loss due to friction in the pipes and also velocity head loss due to changes in direction and also due to constriction in fittings and valves. In this case however the friction factor is to be taken from Moody`s Chart based on the surface roughness of the pipe..

The pressure drop due to friction is given by the formula

$\Delta P = f\, U_m^2\, L / {}_2gd$ ( in meters of water column)

Where L is the equivalent length of the pipe



# Table 4

| Calculation of Friction Pressure Drop in GI Pipes per meter length | | | | | | | |
|---|---|---|---|---|---|---|---|
| At 20 Degree Centigrade with Water | | | | | | | |
| Kinematic Viscosity of Water | | 1.06E-06 | M sq /Sec | | | | |
| | | | | | | | |
| Pipe Size NB | 15 | 20 | 25 | 32 | 40 | 50 | 65 |
| OD meter | 0.0213 | 0.0269 | 0.0337 | 0.0424 | 0.0483 | 0.0603 | 0.0761 |
| Thickness Medium Mtr | 0.00265 | 0.00265 | 0.00325 | 0.00325 | 0.00325 | 0.00365 | 0.00365 |
| ID meter | 0.016 | 0.0216 | 0.0272 | 0.0359 | 0.0418 | 0.053 | 0.0688 |
| Roughness | 0.009 | 0.007 | 0.006 | 0.004 | 0.004 | 0.003 | 0.002 |
| | | | | | | | |
| Flow Litre/Hour | 20 | 50 | 100 | 150 | 300 | 600 | 1200 |
| Velocity | 0.0276 | 0.0379 | 0.0478 | 0.0412 | 0.0607 | 0.0755 | 0.0897 |
| Reynold Number | 417 | 772 | 1227 | 1394 | 2395 | 3777 | 5820 |
| Friction Factor | 0.153 | 0.083 | 0.052 | 0.046 | 0.027 | 0.043 | 0.036 |
| Pressure Drop mm water | 0.373 | 0.281 | 0.223 | 0.11 | 0.12 | 0.236 | 0.214 |
| | | | | | | | |
| Flow Litre/Hour | 30 | 75 | 150 | 225 | 450 | 900 | 1800 |
| Velocity | 0.0414 | 0.0569 | 0.0717 | 0.0617 | 0.0911 | 0.1133 | 0.1345 |
| Reynold Number | 626 | 1159 | 1840 | 2091 | 3592 | 5666 | 8729 |
| Friction Factor | 0.102 | 0.055 | 0.035 | 0.031 | 0.043 | 0.037 | 0.034 |
| Pressure Drop mm water | 0.56 | 0.421 | 0.335 | 0.166 | 0.435 | 0.457 | 0.456 |
| | | | | | | | |
| Flow Litre/Hour | 40 | 100 | 200 | 300 | 600 | 1200 | 2400 |
| Velocity | 0.0553 | 0.0758 | 0.0956 | 0.0823 | 0.1215 | 0.1511 | 0.1793 |
| Reynold Number | 834 | 1545 | 2453 | 2788 | 4789 | 7555 | 11639 |
| Friction Factor | 0.077 | 0.041 | 0.048 | 0.047 | 0.04 | 0.036 | 0.032 |
| Pressure Drop mm water | 0.746 | 0.562 | 0.822 | 0.452 | 0.719 | 0.79 | 0.762 |
| | | | | | | | |
| Flow Litre/Hour | 50 | 125 | 250 | 375 | 750 | 1500 | 3000 |
| Velocity | 0.0691 | 0.0948 | 0.1195 | 0.1029 | 0.1518 | 0.1889 | 0.2242 |
| Reynold Number | 1043 | 1931 | 3067 | 3485 | 5987 | 9443 | 14549 |
| Friction Factor | 0.061 | 0.033 | 0.047 | 0.045 | 0.039 | 0.035 | 0.032 |
| Pressure Drop mm water | 0.933 | 0.702 | 1.258 | 0.677 | 1.096 | 1.201 | 1.191 |
| | | | | | | | |
| Flow Litre/Hour | 60 | 150 | 300 | 450 | 900 | 1800 | 3600 |
| Velocity | 0.0829 | 0.1137 | 0.1434 | 0.1235 | 0.1822 | 0.2266 | 0.269 |
| Reynold Number | 1251 | 2317 | 3680 | 4182 | 7184 | 11332 | 17459 |
| Friction Factor | 0.051 | 0.028 | 0.046 | 0.045 | 0.039 | 0.035 | 0.031 |
| Pressure Drop mm water | 1.12 | 0.843 | 1.773 | 0.974 | 1.578 | 1.729 | 1.662 |
| | | | | | | | |
| Flow Litre/Hour | 70 | 175 | 350 | 525 | 1050 | 2100 | 4200 |
| Velocity | 0.0967 | 0.1327 | 0.1673 | 0.1441 | 0.2125 | 0.2644 | 0.3138 |
| Reynold Number | 1460 | 2703 | 4293 | 4879 | 8381 | 13220 | 20369 |
| Friction Factor | 0.044 | 0.055 | 0.046 | 0.045 | 0.037 | 0.034 | 0.03 |
| Pressure Drop mm water | 1.306 | 2.284 | 2.413 | 1.326 | 2.038 | 2.286 | 2.189 |
| | | | | | | | |
| Flow Litre/Hour | 80 | 200 | 400 | 600 | 1200 | 2400 | 4800 |
| Velocity | 0.1105 | 0.1516 | 0.1912 | 0.1647 | 0.2429 | 0.3022 | 0.3587 |
| Reynold Number | 1668 | 3089 | 4907 | 5576 | 9579 | 15109 | 23278 |
| Friction Factor | 0.038 | 0.052 | 0.046 | 0.043 | 0.036 | 0.033 | 0.029 |
| Pressure Drop mm water | 1.493 | 2.82 | 3.152 | 1.655 | 2.59 | 2.898 | 2.763 |

Cont..



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Flow Litre/Hour | 90 | 225 | 450 | 675 | 1350 | 2700 | 5400 |
| Velocity | 0.1243 | 0.1706 | 0.2151 | 0.1852 | 0.2733 | 0.34 | 0.4035 |
| Reynold Number | 1877 | 3476 | 5520 | 6274 | 10776 | 16998 | 26188 |
| Friction Factor | 0.034 | 0.048 | 0.044 | 0.4 | 0.035 | 0.033 | 0.029 |
| Pressure Drop mm water | 1.679 | 3.295 | 3.815 | 19.485 | 3.187 | 3.668 | 3.497 |
| | | | | | | | |
| Flow Litre/Hour | 100 | 250 | 500 | 750 | 1500 | 3000 | 6000 |
| Velocity | 0.1382 | 0.1895 | 0.239 | 0.2058 | 0.3036 | 0.3777 | 0.4483 |
| Reynold Number | 2085 | 3862 | 6133 | 6971 | 11973 | 18886 | 29098 |
| Friction Factor | 0.058 | 0.048 | 0.044 | 0.038 | 0.035 | 0.032 | 0.028 |
| Pressure Drop mm water | 3.526 | 4.068 | 4.71 | 2.285 | 3.934 | 4.391 | 4.169 |
| | | | | | | | |
| Flow Litre/Hour | 150 | 375 | 750 | 1125 | 2250 | 4500 | 9000 |
| Velocity | 0.2072 | 0.2843 | 0.3585 | 0.3087 | 0.4554 | 0.5666 | 0.6725 |
| Reynold Number | 3128 | 5793 | 9200 | 10456 | 17960 | 28329 | 43647 |
| Friction Factor | 0.054 | 0.045 | 0.041 | 0.036 | 0.034 | 0.03 | 0.028 |
| Pressure Drop mm water | 7.387 | 8.581 | 9.876 | 4.871 | 8.6 | 9.261 | 9.38 |
| | | | | | | | |
| Flow Litre/Hour | 200 | 500 | 1000 | 1500 | 3000 | 6000 | 12000 |
| Velocity | 0.2763 | 0.379 | 0.478 | 0.4116 | 0.6073 | 0.7555 | 0.8966 |
| Reynold Number | 4171 | 7724 | 12267 | 13941 | 23947 | 37773 | 58196 |
| Friction Factor | 0.049 | 0.044 | 0.038 | 0.031 | 0.03 | 0.028 | 0.027 |
| Pressure Drop mm water | 11.917 | 14.916 | 16.272 | 7.457 | 13.49 | 15.367 | 16.08 |

# Table 5

| Calculation of Friction Pressure Drop in GI Pipes per meter length | | | | | | | |
|---|---|---|---|---|---|---|---|
| At 60 Degree Centigrade with Water | | | | | | | |
| Kinematic Viscosity of Water | 0.000000478 | M sq /Sec | | | | | |
| | | | | | | | |
| Pipe Size NB | 15 | 20 | 25 | 32 | 40 | 50 | 65 |
| OD meter | 0.0213 | 0.0269 | 0.0337 | 0.0424 | 0.0483 | 0.0603 | 0.0761 |
| Thickness Medium Mtr | 0.00265 | 0.00265 | 0.00325 | 0.00325 | 0.00325 | 0.00365 | 0.00365 |
| ID meter | 0.016 | 0.0216 | 0.0272 | 0.0359 | 0.0418 | 0.053 | 0.0688 |
| Roughness | 0.009 | 0.007 | 0.006 | 0.004 | 0.004 | 0.003 | 0.002 |
| Flow Litre/Hour | 20 | 50 | 100 | 150 | 300 | 600 | 1200 |
| Velocity | 0.0276 | 0.0379 | 0.0478 | 0.0412 | 0.0607 | 0.0755 | 0.0897 |
| Reynold Number | 925 | 1713 | 2720 | 3092 | 5310 | 8376 | 12905 |
| Friction Factor | 0.069 | 0.037 | 0.053 | 0.048 | 0.041 | 0.038 | 0.033 |
| Pressure Drop mm water | 0.168 | 0.127 | 0.227 | 0.115 | 0.184 | 0.209 | 0.197 |
| | | | | | | | |
| Flow Litre/Hour | 30 | 75 | 150 | 225 | 450 | 900 | 1800 |
| Velocity | 0.0414 | 0.0569 | 0.0717 | 0.0617 | 0.0911 | 0.1133 | 0.1345 |
| Reynold Number | 1387 | 2569 | 4080 | 4637 | 7966 | 12565 | 19358 |
| Friction Factor | 0.046 | 0.053 | 0.047 | 0.044 | 0.04 | 0.034 | 0.031 |
| Pressure Drop mm water | 0.252 | 0.404 | 0.453 | 0.238 | 0.405 | 0.42 | 0.415 |
| | | | | | | | |
| Flow Litre/Hour | 40 | 100 | 200 | 300 | 600 | 1200 | 2400 |
| Velocity | 0.0553 | 0.0758 | 0.0956 | 0.0823 | 0.1215 | 0.1511 | 0.1793 |
| Reynold Number | 1850 | 3426 | 5441 | 6183 | 10621 | 16753 | 25811 |
| Friction Factor | 0.035 | 0.053 | 0.045 | 0.04 | 0.038 | 0.033 | 0.029 |
| Pressure Drop mm water | 0.337 | 0.719 | 0.771 | 0.385 | 0.683 | 0.724 | 0.691 |
| | | | | | | | |
| Flow Litre/Hour | 50 | 125 | 250 | 375 | 750 | 1500 | 3000 |
| Velocity | 0.0691 | 0.0948 | 0.1195 | 0.1029 | 0.1518 | 0.1889 | 0.2242 |
| Reynold Number | 2312 | 4282 | 6801 | 7729 | 13276 | 20941 | 32264 |
| Friction Factor | 0.057 | 0.048 | 0.044 | 0.039 | 0.036 | 0.032 | 0.028 |
| Pressure Drop mm water | 0.866 | 1.017 | 1.178 | 0.586 | 1.012 | 1.098 | 1.042 |
| | | | | | | | |
| Flow Litre/Hour | 60 | 150 | 300 | 450 | 900 | 1800 | 3600 |
| Velocity | 0.0829 | 0.1137 | 0.1434 | 0.1235 | 0.1822 | 0.2266 | 0.269 |
| Reynold Number | 2775 | 5138 | 8161 | 9275 | 15931 | 25129 | 38716 |
| Friction Factor | 0.053 | 0.045 | 0.042 | 0.038 | 0.035 | 0.031 | 0.028 |
| Pressure Drop mm water | 1.16 | 1.373 | 1.619 | 0.823 | 1.416 | 1.531 | 1.501 |
| | | | | | | | |
| Flow Litre/Hour | 70 | 175 | 350 | 525 | 1050 | 2100 | 4200 |
| Velocity | 0.0967 | 0.1327 | 0.1673 | 0.1441 | 0.2125 | 0.2644 | 0.3138 |
| Reynold Number | 3237 | 5995 | 9521 | 10820 | 18586 | 29317 | 45169 |
| Friction Factor | 0.052 | 0.044 | 0.041 | 0.036 | 0.034 | 0.03 | 0.027 |
| Pressure Drop mm water | 1.549 | 1.827 | 2.151 | 1.061 | 1.873 | 2.017 | 1.97 |
| Flow Litre/Hour | 80 | 200 | 400 | 600 | 1200 | 2400 | 4800 |
| Velocity | 0.1105 | 0.1516 | 0.1912 | 0.1647 | 0.2429 | 0.3022 | 0.3587 |
| Reynold Number | 3700 | 6851 | 10881 | 12366 | 21241 | 33505 | 51622 |
| Friction Factor | 0.052 | 0.044 | 0.039 | 0.036 | 0.034 | 0.029 | 0.027 |
| Pressure Drop mm water | 2.023 | 2.386 | 2.672 | 1.386 | 2.446 | 2.547 | 2.573 |
| | | | | | | | |
| Flow Litre/Hour | 90 | 225 | 450 | 675 | 1350 | 2700 | 5400 |
| Velocity | 0.1243 | 0.1706 | 0.2151 | 0.1852 | 0.2733 | 0.34 | 0.4035 |
| Reynold Number | 4162 | 7707 | 12241 | 13912 | 23897 | 37694 | 58074 |
| Friction Factor | 0.05 | 0.043 | 0.038 | 0.035 | 0.033 | 0.028 | 0.027 |
| Pressure Drop mm water | 2.462 | 2.952 | 3.295 | 1.705 | 3.005 | 3.112 | 3.256 |

Cont..



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Flow Litre/Hour | 100 | 250 | 500 | 750 | 1500 | 3000 | 6000 |
| Velocity | 0.1382 | 0.1895 | 0.239 | 0.2058 | 0.3036 | 0.3777 | 0.4483 |
| Reynold Number | 4624 | 8564 | 13601 | 15458 | 26552 | 41882 | 64527 |
| Friction Factor | 0.048 | 0.042 | 0.038 | 0.035 | 0.033 | 0.027 | 0.027 |
| Pressure Drop mm water | 2.918 | 3.559 | 4.068 | 2.105 | 3.71 | 3.705 | 4.02 |
| | | | | | | | |
| Flow Litre/Hour | 150 | 375 | 750 | 1125 | 2250 | 4500 | 9000 |
| Velocity | 0.2072 | 0.2843 | 0.3585 | 0.3087 | 0.4554 | 0.5666 | 0.6725 |
| Reynold Number | 6937 | 12846 | 20402 | 23187 | 39828 | 62823 | 96791 |
| Friction Factor | 0.045 | 0.041 | 0.037 | 0.034 | 0.032 | 0.027 | 0.026 |
| Pressure Drop mm water | 6.156 | 7.818 | 8.912 | 4.601 | 8.094 | 8.335 | 8.71 |
| | | | | | | | |
| Flow Litre/Hour | 200 | 500 | 1000 | 1500 | 3000 | 6000 | 12000 |
| Velocity | 0.2763 | 0.379 | 0.478 | 0.4116 | 0.6073 | 0.7555 | 0.8966 |
| Reynold Number | 9249 | 17128 | 27203 | 30915 | 53104 | 83763 | 129054 |
| Friction Factor | 0.044 | 0.038 | 0.036 | 0.033 | 0.032 | 0.026 | 0.025 |
| Pressure Drop mm water | 10.701 | 12.882 | 15.416 | 7.938 | 14.389 | 14.27 | 14.889 |

Chapter 12

# Designing of Heat Exchangers for Solar Water Heating Systems

**Introduction**

Heat exchangers are devices which isolate the fluid flowing through the solar collector from the water which is meant to be heated. These devices create a physical barrier between the fluid in the collectors and the water being heated. This barrier however permits the movement of heat from fluid in collector panels and the water to be heated.

**Objective**

This chapter intends to provide the designers information about the type heat exchanger and means of calculating the heat transfer coefficient and area required for some types of the heat exchangers used in solar water heating systems.

Heat exchangers are used in solar water heating systems in following situations

**1.** When the systems are located in regions where night temperature are likely to cause freezing of water in the collectors. As the volume of ice formed is higher than that of liquid water this may cause rupture of the tube. An antifreeze solution is used as working fluid in these cases in the collectors. The heating of water is done with heat exchange between this fluid and water in a heat exchanger.

**2.** When water has temporary hardness which tends to deposit in the collector tubes in the process of heating and may choke collector tubes.

**3.** When water to be used may be corrosive to the material of collector and may cause damage to collector material

**4.** When the pressure of water to be heated is much higher than that the collector is designed to sustain on long term use basis.

The function of the heat exchanger is to deliver heat to the water to be used using a medium which is generally different from the water being heated. This medium may be water of a different quality or a heat exchange fluid.

The process of heat exchange involves the following:

a) Flow of the heat exchange fluid through the collector system.

b) Flow of heat exchange fluid through the heat exchanger

c) The transfer of heat to water in use which may also be moving through another adjoining space in the heat exchanger or may be stationery except for convection currents

d) In this process the water to be used gets heated up and the heat exchange fluid gets cooled and is sent to solar collector for further heating up.

e) The process of heat exchange requires a difference in temperature between the heating fluid and the water and a surface which isolates the heat exchange fluid from water

f) The design of heat exchanger is done to determine the area of the heat exchange surface required for efficient heat transfer under specified conditions.

g) As the flow of heat exchange fluid is an essential condition for heat transfer, there has to be a provision for flow to be maintained in the overall design of the system.

Heat exchangers have been used for both the thermo-siphon systems as well as forced flow systems. The design adopted for the systems are different.

Heat exchangers for forced flow systems

**1.** Shell and tube type heat exchangers.

This type of heat exchangers has one fluid in the tubes generally arranged in a U tube fashion attached to a tube sheet. The flow of one fluid takes place through the tubes and other through shell containing these tubes. The method of designing these heat exchanger done generally by flowing a procedure given in TEMA (Tubular Exchangers Manufacturer`s Association) hand book. These have not been successful with solar water heating systems due to requirement of a relatively large temperature difference between the working fluid and water.

**2.** Plate type heat exchanger

These types of heat exchangers have heat exchange surface arranged in the form of plates which are stacked in the form of a pack with gaskets in between. The fluid passages are formed by alternating interspaces between the plates. The area of heat exchange depends on the geometry of fluid passages. Interspaces are very fine and generally high fluid velocities are used to obtain good heat transfer. The design depends on individual manufacturer`s design pattern and is provided by the manufacturer as per specified conditions. Pressure drops are high and relatively higher pumping energy is required.

The heat exchanger is very compact.

**3.** Tube in tube type heat exchanger

These heat exchangers use coaxial tubes with one fluid flowing in the inner tube and the second fluid flowing in the annulus between the tubes. A number of tubes may be arranged in a series parallel configuration to obtain required flow. These heat exchangers are relatively easy to manufacture and also provide heat transfer with reasonable temperature differential. The tubes are arranged in counter flow arrangement to get a good temperature profile for water and working fluid. Examples of designing of this type of heat exchangers are being given in the design of forced flow systems.

The design of this type of heat exchangers can be carried out by using the following data

S= Size of the solar water heating system in litre/day

Mp = design flow rate for the heat exchanger for the primary circuit of the heat exchanger

=Ms(Tso-Tsi)/(Tpi-Tpo)

Ms= design flow rate for the heat exchanger for the secondary circuit of the heat exchanger generally taken as S/5 in litres/hr

$T_{pi}$ =Input temperature of primary fluid

$T_{po}$ = outlet temperature of primary fluid

$T_{si}$ = Inlet temperature of secondary fluid

$T_{so}$ = Outlet temperature of Secondary fluid

$d_i$ = Inside diameter of the inner tube chosen for the heat exchanger in meters

$d_o$ = outside diameter of the inner tube chosen for the heat exchanger in meters

$D_i$ = Inside diameter of the outer tube chosen for the heat exchanger in meters

$D_o$ = Outside diameter of the outer tube chosen for the heat exchanger in meters.

n = number of parallel path chosen for the heat exchanger

$t_p$ = average temperature of primary fluid through the heat exchanger in degree C

$t_s$ = average temperature of the secondary fluid through the heat exchanger in degree C

k = thermal conductivity of water at the temperature

**v**= Kinematic viscosity of the fluid at the temperature in meter 2/second

$U_p$= Velocity of water in the annulus for the primary circuit flow in meter/ second

$U_s$ = Velocity of water in the secondary circuit in the inside tube meter/ second

Dea= Equivalent diameter of the annulus for the purpose of heat transfer in meters



De = Equivalent diameter of the annulus for calculating friction loss through the heat exchanger in meters

Rep= Reynold`s number on the primary side or the annulus, dimensionless

Res= Reynold`s number for the secondary side or the inner tube, dimensionless

Nup = Nusset number for the primary circuit for the heat exchanger, dimensionless

Nus= Nusset number for secondary circuit for the heat exchanger, dimensionless

Pr = Prandl number for water at the temperature of the fluid, dimensionless

F= Fouling factor

hi = Heat Transfer coefficient of the inner tube surface

ho= Heat transfer coefficient of the outer surface of inner tube

H = over all heat transfer coefficient

Q= Amount of heat transfer in Kcal/hr

A = Area required for heat transfer in Square meters

l = length of each double pipe in meters

L= total length required for heat transfer area in meters

The calculations are carried out as follows

$Up = Mp / \{n(\pi/4 \times (Di^2 - do^2)\}/1000$

$Us = Ms / \{n(\pi/4 \times di^2)\}/1000$

$Dea = (Di^2 - do^2)/do$

Rep = Up x Dep / **v**p

Res = Us X di /**v**s

Nup=0.036 Rep0.8 Pr0.33 (l/Dea)0.055

Nus = .023 Res0.8 Pr0.4

hi = Nus k/di

ho = Nup k/ Dea

H=1/[1/(hido/di)+(1/ho)+F)

LMTD = {(Tpi-Tso)-(Tpo-Tsi)}/LN{(Tpi-Tso)/(Tpo-Tsi)}

Q = Ms (Tso-Tsi) considering specific heat and specific gravity of water as one

Q= H x LMTD x A

A= Q/( Hx LMTD)

L=A/($\pi$ do)

Length of each pass= L/n

No of tubes required in series = Length of each pass/l

Based on the configuration generated the pressure drop of the heat exchanger in the primary and secondary mode can be calculated.

4) Coil type heat exchanger

This design utilizes a coil formed from a tube through which one of fluid flows and the other fluid or water is in the storage tank. The fluid in the storage tank is stationery except for convection currents. Examples of designing of this type of heat exchangers are being given in the design of forced flow systems.

For this type of heat exchanger the calculation of the primary side heat transfer coefficient is done as in case of the inside tube in tube and tube heat exchanger and the tank side coefficient is calculated as if the system is in natural circulation as given in



# Table 6

| Calculations for Coil type Heat Exchanger - Thermosiphon Systems | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| System Size | **500** | **LPD** | | | | | | |
| Tube Dia | 0.02540 | | | | | | | |
| Thickness | 0.0016 | | **Tank side Water** | | | **Collector side water** | | |
| T tank inlet | 20 | °C | hc | | | $h_h$ | | |
| T tank top | 60 | °C | water properties at avg temp | | | water properties at avg temp | | |
| T collect oulet | 70 | °C | 40 | | | 50.00 | | |
| T collect inlet | 30 | °C | ρ | 992.3 | | ρ | 986 | |
| Flow collector | 100 | LPH | μ | 6.50E-04 | | μ | 5.04E-04 | |
| | | | √ | 6.59E-07 | m²/sec | √ | 5.56E-07 | |
| Q | 4000.0 | Kcal | Pr | 4.31 | | Pr | 3.54 | |
| | 4648.0 | W | K | 0.634 | | K | 0.648 | |
| | | | b | 0.000387 | Unit | b | 0.000449 | |
| For Counter flow | | | | | | $D_h$ | 0.0222 | mm |
| θ1 | 10 | | Gr | 7.16E+05 | m/sec | $V_m$ | 0.07 | m/sec |
| $\theta_2$ | 10 | | Nuo | 0.36 | | Re | 2.86E+03 | |
| $\theta_m$ | 10 | | Nu | 24.18 | | Nu | 2.22E+01 | |
| f | 0.0005 | | ho | 603.53 | | $h_h$ | 649.01 | |
| h | 255.11 | | A | 1.82 | m² | Length | 22.83 | Meter |
| **Calculation of Pressure drop in Coil** | | | | | | | | |
| Tube Flow | Re | 8680 | | | | | | |
| | f | 0.032 | | | | | | |
| | Length | 22.83 | | | | | | |
| | V | 0.07 | | | | | | |
| Pressure Drop | ΔP | 8.6365 | | | | | | |
| Velocity head | | 0.262 | | | | | | |

# Table 7

| Calculations of Coil type Heat Exchange - Forced Flow Systems | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| System Size | **8000** | LPD | | | | | | |
| Tube Dia | 0.02540 | | | | | | | |
| Thickness | 0.0016 | | **Tank side Water** | | | **Collector side water** | | |
| T tank inlet | 20 | °C | hc | | | $h_h$ | | |
| T tank top | 60 | °C | water properties at avg temp | | | water properties at avg temp | | |
| T collect oulet | 70 | °C | 40 | | | 50.00 | | |
| T collect inlet | 30.00 | °C | ρ | 992.3 | | ρ | 986 | |
| Flow collector | 1600 | LPH | μ | 6.50E-04 | | μ | 5.04E-04 | |
| | | | √ | 6.59E-07 | m²/sec | √ | 5.56E-07 | |
| Q | 64000.0 | Kcal | Pr | 4.31 | | Pr | 3.54 | |
| | 74368.0 | W | K | 0.634 | | K | 0.648 | |
| | | | b | 0.000387 | | b | 0.000449 | |
| For Counter flow | | | | | | $D_h$ | 0.0222 | mm |
| θ1 | 10 | | Gr | 7.16E+05 | | $V_m$ | 1.15 | m/sec |
| $\theta_2$ | 10.00 | | Nuo | 0.36 | | Re | 4.58E+04 | |
| $\theta_m$ | 10.00 | | Nu | 24.18 | | Nu | 2.04E+02 | |
| f | 0.0005 | | ho | 603.53 | | $h_h$ | 5964.11 | |
| h | 425.76 | | A | 17.47 | m² | Length | 218.90 | Meter |
| **Calculation of Pressure drop in Coil** | | | | | | | | |
| Tube Flow | Re | 4.58E+04 | | | | | | |
| | f | 0.018 | | | | | | |
| | Length | 218.90 | | | | | | |
| | V | 1.15 | | | | | | |
| Pressure Drop | ΔP | 11.9231 | Meter water column | | | | | |
| Velocity head | | 0.0672 | Meter water column | | | | | |



# Table 8

| Calculations for "Tube in Tube" type Heat Exchanger (Forced Flow Systems) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size of system | 10000 | Litre Per day | Temperature | | 60 | Deg C | | | T mean | | | |
| Primary Flow rate | 2285.71 | Litre per hour | Temperature | | 65 | Deg C | 30 | Deg C | 47.5 | | | |
| Secondary Flow rate | 2000 | Litre per hour | Temperature | | 60 | Deg C | 20 | Deg C | 40 | | | |
| Flow conditions | Counter Flow | | Primary in annulus and Secondary in inner Tube | | | | | | | | | |
| Length Of Individual tubes | 2.7 | Metres | Material of Tubes | | SS 304 L | | | | | | | |
| | OD | Thickness | ID | Area | Velocity | Equivalent dia | K Viscosity | Conductivity | Reynold | Prandtl | Nusset | Heat trans Coefficient h |
| | Metres | Metres | Metres | sq Metres | M/Sec | dia Meter | SqM/ Sec | W/m-K | No | Pr | Nu | W/sqm -K |
| Outer Tube | 0.0381 | 0.0012 | 0.0357 | 0.0010 | | | | | | | | |
| Inner Tube | 0.0254 | 0.0012 | 0.023 | 0.0004 | 1.337 | | 0.000000659 | 0.634 | 46668 | 4.31 | 224.3 | 3982.524569 |
| Annulus | | | | 0.0005 | 1.285 | 0.0248 | 0.000000582 | 0.645 | 54685 | 3.73 | 265.0 | 6898.050016 |
| Fouling factor | | 0.0005 | Ignoring Metal Resistance as negligible | | | | | | | | | |
| Over all heat transfer coefficient | | | 1084.284774 | W/sqm -K | | | | | | | | |
| Q | | 80000 | Kcal/Hr | 93240 | W | LMTD | 7.21 | deg C | | | | |
| Area Required | | 11.92 | Sq Metre | | No of tubes | 55.33 | 56 | | | | | |
| **Calculation of Pressure Drop Through Heat Exchanger** | | | | | | | | | | | | |
| | **Primary Side** | | | | **Secondary Side** | | | | | | | |
| Length | 151.2 | Metres | | | 168 | Metres | | | | | | |
| Dia | 0.0103 | Metres | | | 0.023 | Metres | | | | | | |
| Re | 22733 | | | | 46668 | | | | | | | |
| f | 0.028 | | | | 0.024 | | | | | | | |
| Friction Pressure Loss | 34.57 | Meter water column | | | 15.98 | Meter water column | | | | | | |
| Velocity Head | 0.08 | Meter water column | | | 0.091130 | Meter water column | | | | | | |
| Loss due to velocity head | 4.71 | Meter water column | | | 5.10 | Meter water column | | | | | | |
| **Total Pressure Drop** | **39.28** | Meter water column | | | **21.08** | Meter water column | | | | | | |

# Table 9

| Calculation of Thermosiphon Jacket type Heat Exchanger | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Heat Exchanger** | 100 | LPD | | | | | | |
| *Dia of Tank* | *0.39* | mtr | mtr | Jacket Length | Tank | 0.39 | Equvalent | 0.03826087 |
| *Dia of jacket* | *0.41* | mtr | | 0.22 | dia | | dia | |
| | | | | | **Tank side Water** | | **Collector side water** | |
| Cold Inlet to Tank | $T_{ci}$ | 20 | °C | | hc | | $h_h$ | |
| Hot outlet from tank | $T_{ce}$ | 60 | °C | | water properties at avg temp | | water properties at avg temp | |
| inlet to H.E. | $T_{hi}$ | 70 | °C | Average Temp. | | 40 | | 50 |
| Cold return to Collectors | $T_{he}$ | 30 | °C | | ρ | 992.2 | ρ | 988.1 |
| | | | | | μ | 0.000653 | μ | 0.648 |
| Flow through H.E. | $m_h$ | 20 | LPH | Kinematic viscosity | √ | 6.59E-07 | √ | 6.56E-07 |
| Heat Load | Q | 800 | Kcal | | Pr | 4.31 | Pr | 3.54 |
| | | 929.6 | W | thermal conductivity | K | 0.634 | K | 0.648 |
| | | | | Volumetric Coefficient | b | 0.000387 | b | 0.000449 |
| For Counter flow | | | | Tank diameter | $D_h$ | 0.39 | $D_h$ | 0.03826087 |
| | θ1 | 10 | | Velocity | $V_m$ | - | $V_m$ | 0.002525253 |
| | $θ_2$ | 10.00 | | Reynolds No. | Re | | Re | |
| LMTD | $θ_m$ | 10.00 | | Grasoff no | Gr | 1.03713E+10 | Gr | 1.15E+07 |
| | | | | Nusset No initial | Nuo | 0.36 | Nuo | 0.36 |
| | | | | Nusset No | Nu | 480.22 | Nu | 51.56 |
| | | | | heat transfer coeffient | ho | 780.67 | hi | 873.28 |
| | | | | Fouling Factor | f | 0.0005 | | |
| | | | | | h | 341.7562362 | | |
| Heat transfer Area | A | 0.27 | | Jacket length required | | 0.22 | | |





# Selection of Pumps for Solar Water Heating Systems

**Introduction**

Pumps are required in solar water heating systems whenever conditions are not conducive to use of thermo-siphon or natural circulation type of systems. The pumps have to ensure the desired flow rate of water or heating fluid.

**Objective**

This chapter intends to provide designers and installers of solar systems with the requirements of calculations before a pump for solar water heating system may be specified in terms of required head and the flow rate of the pumps. The means of calculations have been provided elsewhere in the book.

The selection of the pump for solar water heating system requires specifying the following parameters for the operation of the system

1. Flow rate required in the solar water heating system
2. The pressure drop in the in the solar water heating system for the required flow rate
3. The temperature of operation of the solar water heating system.

The flow rate required in the solar water heating system is obtained from the details given in the chapter on flow rate for solar water heating system.

Based on the flow rate we should calculate the velocity of flow through different parts of the solar water heating system

a. The collector arrays
b. Interconnecting piping
c. Heat Exchanger
d. Velocity head

The pressure drop in the collector arrays is to be added if the collectors are in series and is to be considered only once if the collector are arranged in parallel configuration.

The pressure drop through the inter connecting piping is calculated for each branch line and added in case of series configuration and or considered for only one of the branches for parallel configuration. The pressure drop in trunk lines is calculated and added to the total pressure drop.

The pressure drop through the heat exchanger is to be considered for primary system flow if the heat exchanger is tube and tube type. For coil type heat exchangers placed inside the hot water storage tank the pressure drop through the coil is considered.

The loss of velocity head is considered whenever there is a change in flow velocity within the solar water heating system. There is a change in flow velocity when the water is taken from or returned to hot water storage tank. The velocity inside the tank becomes negligible or zero for all practical purpose.

The pump to be used is chosen based on the head required for the flow rate and the highest temperature to which it may be exposed during its operation at any time in the solar water heating system.





# Design of storage tanks

**Introduction**

The hot water storage tanks form an important part of the solar water heating system. These tanks store the hot water which is generated during the day and facilitate its use in the period when no hot water is being generated by the solar water heating system.

**Objective**

The objective of this chapter is to make designers and installers aware of the operating conditions of hot water tank. It will also deal with methods available in IS 2825 for designing the tanks when these are required to be designed as pressure vessels.

The storage tanks are subjected to high temperatures when the water is not used regularly. It is subjected to pressure of the cold water which is connected to the system and at times to extra pressure created by expansion of water in the system when there is a non-return valve provided in cold water supply to the hot water storage tank.

**Two types of design are used in the hot water storage tank**

1. Hot water storage tanks not subjected to pressure

Hot water storage tank which are subjected to limited gravitational head generally less than 5 meter of water column at maximum filling of cold water tank. Such tanks are designed as non-pressure tanks and are vented to atmosphere at the highest point. These tanks are tested at 0.6 to 0.8 Kg / $cm^2$ pressure. In some solar water heating systems the storage tank is used only for filling in hot water as it is generated and tank is never completely filled as the storage tank has a level controller, such tanks may be designed as vertical tanks as per API Code for vertical tanks.

2. Hot water storage tanks subjected to pressure

These tanks are to be designed as per IS:2825 the code for design of unfired pressure vessels. The design requires ascertaining the pressure and temperature, which the tank may be subjected to during the operation of the solar water heating system. The code gives detail procedure for designing of the storage tank. Some of the features are briefly described below but these are only for explanation and design must be carried out using the code.

Practically all pressure vessels are cylindrical and the ends of the tank have to be dished ends.

For Cylindrical tanks the shell thickness is given by

$t = {}_pD_i/(200fJ-p) = {}_pD_o/(200fJ+p)$

Where

t= required minimum thickness of the shell in mm

p= Design pressure of the tank in kgf/mm2

$D_i$ = Inside diameter of the tank in mm

$D_o$ = Outside diameter of the tank in mm

f = Allowable stress in kgf/$mm^2$ at the design operating temperature for material as specified in the code

J = Joint factor (given by the type of welding done and the quality control on welding joint)

There are other factors coming into determining the shell thickness which require determining the longitudinal stress on the shell due to the support arrangement.

An effective corrosion protection must be provided for the tank or a corrosion allowance adequate for the design life of the tank must be provided as additional thickness.

The domed ends of hemispherical, semi-ellipsoidal or dished shape are also calculated as per the code with the following limitations

1. The inside radius of the dishing shall not be greater than the diameter Do and

2. The inside corner radius shall preferably be not less than 10 percent of inside diameter and in no case less than 6 percent nor less than 3t.

3. The openings in the dished ends shall be accounted for in the calculation or compensated by adding reinforcement around the opening

Thickness of the ends is calculated by using the following formula for ends concave to pressure



$t = {}_pD_oC/(200fJ)$

Where

C= A shape factor obtained from diagram in the code based on the ratio of height of the dished end to the external diameter $D_o$ and the ratio t/ $D_o$ and also the ratio d/SQRT(t $D_o$) where d is the diameter of uncompensated opening.

At times it is difficult to obtain dished ends and conical ends may be used for low pressure applications. The code gives detail procedure for design of such ends also.

For very small tanks it may be possible to use flat ends and the thickness of such ends is calculated as per the following

t = CD X SQRT (p/f)/10

Where C is a factor depending on the method of attachment of the end to the shell as given in the code IS 2825.

The details of attaching manhole openings and the flange covers for these openings also are to be calculated as per the procedure given in the code.

Chapter 15

# Material selection for Piping, Tanks and Heat exchangers and role of water quality

**Introduction**

The quality of water used in the solar water heating system has very large role to play in the longevity of the solar water heating systems. Hence, the material selection made while ignoring the quality of water results in loss of the system components due to scaling or corrosion.

**Objective**

The objective of the chapter is to impress upon the designers and installers of the solar water heating system the importance of the quality of water being in solar water heating application. This quality is to be considered when designing the solar water heating system and also in choosing the materials for various components of the solar water heating system.

**Water Quality**

Various types of water compositions and the limitations on material used with these are indicated below.

**Temporary hard water**

When temporary hard water is heated, dissolved material in water separates.

The dissolved matter is in the form of bicarbonates of calcium and magnesium which are highly soluble in water. However, these bicarbonates get converted to carbonates of calcium and magnesium in the process of heating. The carbonates of calcium and magnesium are not soluble in water. The basic chemical reactions are represented by following chemical equations

$$C_a(HCO3)2 \longrightarrow = C_a Co_3 + Co_2 + H_2 o$$

Similar reaction takes place in case of magnesium bicarbonate also.

The carbonates, thus, released accumulate in different parts of the collector system. These are at times accompanied by Silica and other colloidal material existing in water.



This process is called scale formation. Formation of scale is faster in FPC based system than in ETC based system. However, scale formation takes place in ETC based system as well. In such kind of water, indirect heating through heat exchanger is recommended. In case of indirect heating, scale formation takes place at the heat exchanger surface, which can be easily cleaned at periodic intervals

**Permanent hard water**

Permanent hard water does not create problem in the performance of FPC or ETC based system. However, if the system remains filled with water during summer and is overheated continuously, this results in building up of the concentration of the dissolved solids. When the concentration build up goes beyond the solubility limit of the material, this causes formation of scale. This scale may build up over a period of time and may create problem in the functioning of the system. The easiest way to avoid formation of this type of scale is to drain the solar water heating system when it is not likely to be used for prolonged period of time. This is however very difficult in case of directly coupled ETC Systems. In case of such systems these may be covered to avoid overheating and scale formation. Sulphates of calcium and magnesium and silica are the major contributor to this scale formation

**Saline Water**

The common salt, chlorides and fluorides of calcium & potassium, nitrates of sodium & potassium form part of saline waters.  The composition may vary from place to place

Saline water corrodes mild steel, galvanized piping as well as stainless steel. Copper is not affected to a great extent. Therefore, in saline atmosphere both Flat Plate Collectors and Evacuated Tube Collectors can be used. However, stainless steel storage tank must be avoided. Instead mild steel storage tank can be used with proper treatment and paint protection. Regular maintenance of other components is necessary in saline water use. The Ph value of water plays an important role in corrosion, with Ph higher than 8 being mildly protective and lower than 7 being highly corrosive.

**Acidic Water**

Acidic water is corrosive to mild steel, galvanized iron, copper and other metals. It is also corrosive to stainless steel if the water contains sulfides, chlorides and fluorides. ETC based systems should be used in such water conditions. However, such water quality is rare but may exist in areas where ground water or river water has been polluted by industrial effluents. A Ph value of less than 6 will not be tolerated by most metals if it is due to reducing acids and may be tolerated by some metals if it is to due oxidizing acids.

**Alkaline Water**

This is the most common water and moderate alkalinity is tolerated by mild steel, copper, stainless steel and galvanized iron. However, galvanized iron starts losing zinc which deposits on copper surfaces in the same system. Both Flat Plate Collectors and Evacuated Tube Collectors can be used in such water conditions. Insulated PVC pipes may be used instead of GI pipes to avoid zinc depletion.

**Water with high turbidity**

Turbidity in water is because of high amount of suspended solids. These solids will settle down slowly when the water stays for a long time in any container. These suspended solids are often charged particles. The charge gets neutralized slowly in contact with metals and slow settling takes place. Turbid water should be avoided in solar water heating systems as it affects both, the FPC as well as the ETC systems. If turbidity in water cannot be avoided, periodic maintenance must be carried out for reliable and smooth operation of the system

**Treated water (for removing hardness)**

Water treatment is usually done before feeding into the boiler in order to remove hardness.

The most common type of treatment is to replace salts which have low solubility with sodium chloride. However, hardness removal process makes water saline and in the process corrosive to metal components. This water is not suitable for either FPC or ETC and should be used with precautions to avoid damage to the solar water heating system components. This water is not suitable for stainless steel tank also.



Chapter 16

# Various control mechanisms for Solar Water Heating systems

**Introduction**

The heating in the solar water heating systems takes place during the sunshine hours only. Whenever we use a pump for ensuring the flow of water we have to devise means of controlling the pump so that it operated only when it is required to operate. This makes the use of a controlling system essential. Also if any auxiliary heating device is incorporated in the solar water heating system, that device also should be constrained to work only when required.

**Objective**

The objective of this chapter is to explain the devices being used for controls in solar water heating systems.

**Control Mechanisms**

The solar water heating system, which is operating with the help of a pump for ensuring the flow of water in the system, have to incorporate a minimum of one type of control to switch on or switch off the operation of the pump. Two types of controls are used for primary circulation system of solar hot water system.

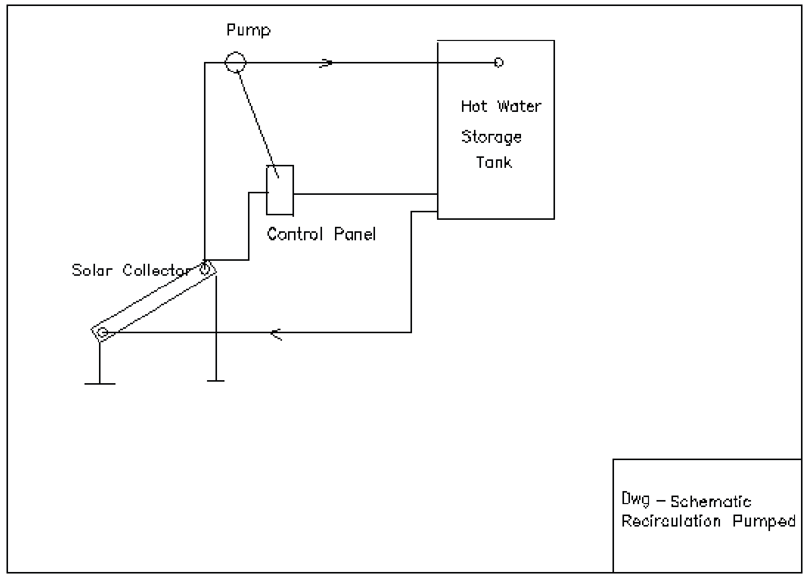
1. <u>Differential temperature controller</u>

This type of controller works on the basis of adjusting the pump operation to a minimum temperature differential between the solar collector plate or outlet and the temperature inside the storage tank. The differential is normally set at 5 0 C. There are two temperature probes installed with RTD to measure the temperature. The measurement signal from these probes is fed to a controller which switches on the pump. The system in such case is recirculation type and circulation of water between the tank and collectors starts and continues as long as the difference is equal or higher than the set value. This ensures transfer of heat to the storage tank from the solar collectors as long as there is sufficient sunshine on the collector.

When used with a heat exchanger both sides of heat exchanger may be operated by the same controller or more than one controller may be used.

The hot water storage tank, in this case, is always kept full. The hot water to be used is drawn from the top of the tank. Supply of hot water from storage tank requires equivalent amount of supply of cold water at the bottom of the hot water tank so that the constant level of water is maintained.

In these systems the mixing of water tends to decrease the temperature of water as withdrawal of water takes place.



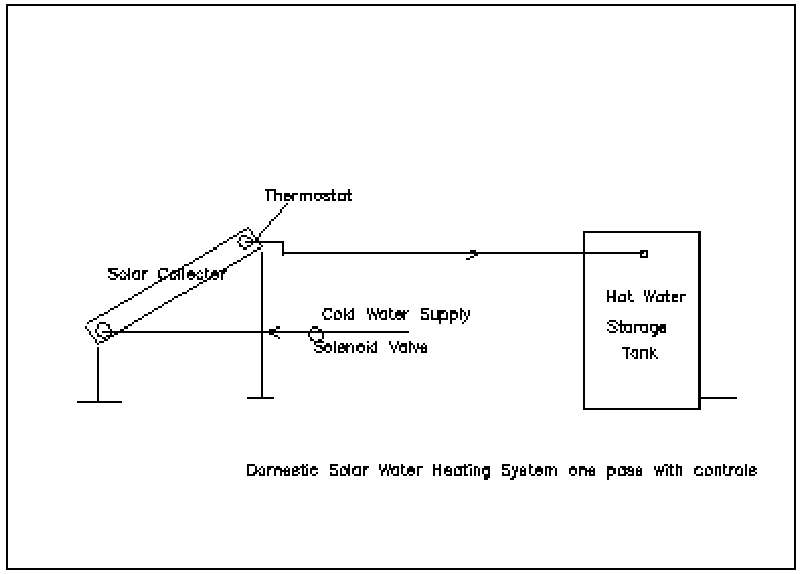

Differential Temperature Controller in a Solar Water Heating System

2. Thermostatic temperature controller

This type of controller are used invariably when the solar water heating system is not recirculation type and the design conditions for the solar system are that the hot water should not be sent to the storage tank unless the water has reached a minimum temperature.

The hot water storage tank in this case in not kept full and water is drawn from a connection near the bottom of the tank. A level controller is required in the storage tank to ensure that the solar system can be shut down when the level of water has reached the top of the tank and there is no overflow. This imposes restraint on the system as it may cause overheating in the solar system when the pump is shut off.

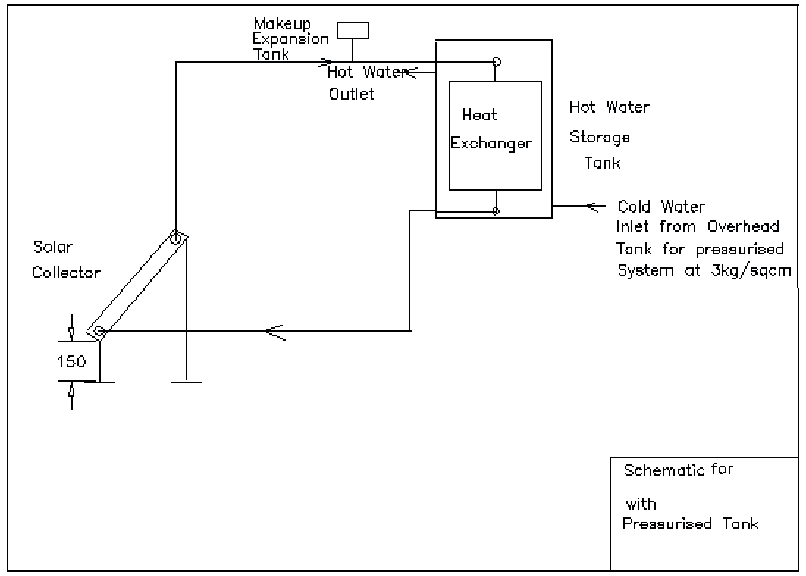


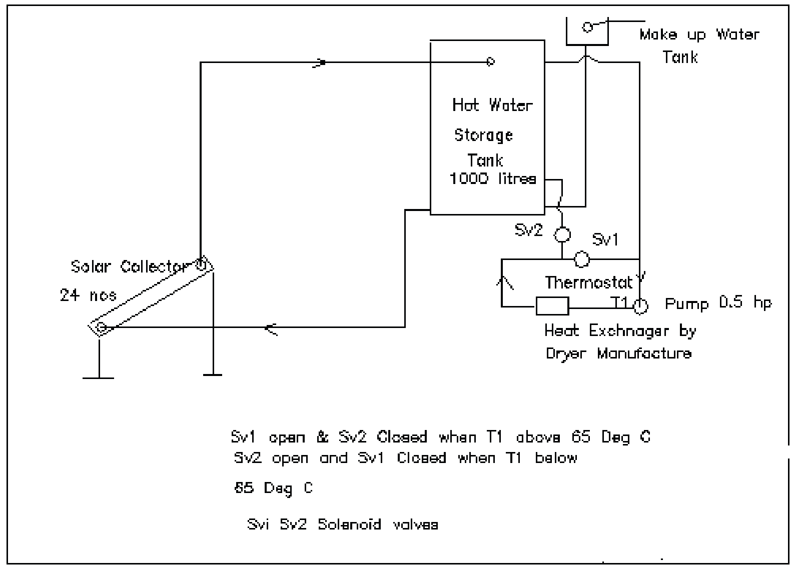



Solar Water Heating System with a Thermostatic type Controller

3. Thermostatic controller for the backup system.

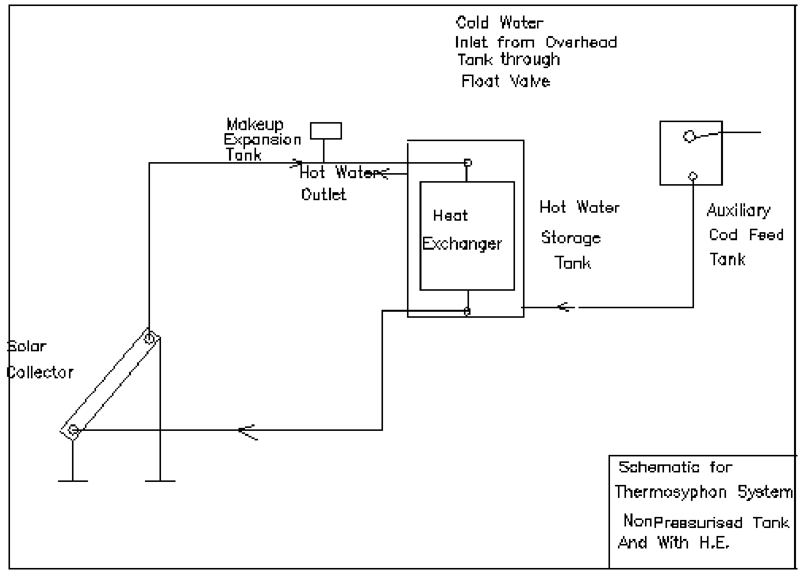
A thermostatic control is essential whenever a backup system is installed with the solar water heating system to ensure that the water is not heated up beyond the required level and consumption of energy is not beyond what is required for the system.




Solar Water Heating System with controls on the user end, (for Drying Installed at SBL Limited for Lactose Drying)






Solar Water Heating system without controls used with a high pressure cold supply

Chapter 17

# Thermo-siphon solar water heating systems

**Introduction**

Solar water heating systems are broadly classified in two categories namely, the thermo-siphon systems or forced flow systems based on way the flow of water or heating fluid in the collector takes place.

**Objective**

Thermo-siphon water heating systems have been used for majority of installations in the country. This chapter also intends to emphasize the importance of these systems and to assert that these systems are amenable to design interventions to create long lasting solutions.

In this type of solar water heating systems the flow of water or heating fluid takes place due to density differential created as the water or heating fluid is heated up. The heating of water or heating fluid occurs by solar radiation falling on the solar collector surface. The hot water tank is always placed on top of the collector level.

It has been normally felt that these systems do not require many engineering inputs or calculations for their design. However, this is a misconception. Design of these systems also requires careful analysis of the requirements and operating conditions. These systems are also amenable to analysis and design variation which can be worked out in detail.

In the next chapters we shall be discussing on i) pressure available for such systems ii) piping design for such systems iii) heat exchanger design for such systems and iv) Examples of design of some of such systems

**Deciding Design Parameters for thermo-siphon solar water heating systems**

The design parameters for thermo-siphon solar water heating systems can be decided with the following

a) The solar heat is collected on as and when available basis. The use pattern is on as and when required basis. There is a need for matching these two requirements. This is done by using a storage device in the form of Hot Water storage Tank. The Capacity of the Hot Water Tank is decided to balance the chronological mismatch between the supply and the demand.

b) When solar heating is available and demand also exists the system must be in a



position to deliver the hot water. This condition imposes a restriction that generation must be at the required or higher than the required temperature.

Supposing we are designing a system with capacity of tank equal to the demand of hot water say at a temperature 60 0C. Also water below 450C will not be useful and we have the requirement during the day also. If a system of 100 liter capacity is designed for flow rate of 50 liter/hour. The tank will get heated to 600C in 6 hrs of sunny period but it will require 3 circulations for the temperature to be built up to 600 C. Which means temperature at the top of the tank will lower than required after first circulation of tank water through the collector. This means water at useful temperature will be available only in the afternoon period after previous days heating has been used up. However if circulation rate is to be between 20-30 liter/hour, water reaching the top of the tank is at useful temperature in the first circulation itself and it is instantly available.

We are able to decide tank capacity and water flow rate accordingly.

**Example for deciding flow rate:**

| | |
|---|---|
| Capacity of tank | : equal to the total day demand |
| Temperature of Hot water required | : 60 deg. C |
| Water below 450C | : not useful for meeting the demand |
| Water requirement | : during the day also |
| System capacity design | : 100 Ltr |
| Input water temperature | : 20 deg. C |
| Time required for heating 100 Litres | |
| of water up to 60 deg. C | : 6 hours |
| Heat delivered in one hour | = 100 x (60 – 20) / 6 = 667 |

**Case I**

| | |
|---|---|
| Flow rate | : 50 lit per hour |
| Temperature of water after one hour | = 20 + 667 / 50 = 33.4 deg. C which is less than |
| at the outlet of the tank | 45 deg. C & hence not useful |
| Temperature rise in one hour/pass | : 13.4 deg.C |
| Temperature differential to attain | : 60 – 20 = 40 deg.C |
| No. of circulations needed | : 40 / 13.4 = 3 |

We can see from the above that after the first pass the hot water temperature was 33.4 which were not useful. Also, the water would need three circulations to attain 60 deg. C temperature.

**Case II**

| | |
|---|---|
| Flow rate | : 30 lit per hour |
| Temperature of water after one hour at the outlet of the tank | = 20 + 667 / 25 = 46.7 deg. C which is more than 45 deg. C & hence useful |
| Temperature rise in one hour/pass | : 26.7 deg.C |
| Temperature differential to attain | : 60 – 20 = 40 deg.C |
| No. of circulations needed | : 40 / 26.7 = 1.5 |

We can see from the above that after the first pass the hot water temperature was 46.7 which was useful. Also, the water would need one and half circulations to attain 60 deg. C temperature.

Hence, we can decide water flow rate accordingly.

**Storage tank:** After deciding the capacity of storage tank, we have to decide other design parameters of the tank. The operating and design pressure of the storage tank and tank material. The design pressure is the expected highest operating pressure of the system and the material of the tank is decided by the compatibility of the material with the quality of water being used.

**Collector tilt:** The seasonal variation in demand decides the optimization of the collector tilt.

**Direct or Indirect Heating type:** The temporary hardness level of water decides whether the system can be direct heating type or indirect heating type with heat exchanger to be built in the circuit. Heat exchanger can also be used to isolate collectors from the high pressures on the user side.

**Heat Exchanger:** If heat exchanger is required, the capacity of heat exchanger should be such that at the required flow rate can be maintained and the heat can be transferred without raising the collector outlet temperature significantly.

**Collector layout and piping:** The Collector layout is decided based on the space available and the distance required between the Collector rows. A tentative schematic of piping can be made based on this layout. Having decided these parameters and also the routing of the collector piping we can calculate and choose the pipe sizes which will be suitable for providing the desired flow rate.





# Pressure available for flow in thermo-siphon system

**Introduction**

As the name implies, the flow of heating fluid or water in this type of solar water heating systems is taking place on account of head developed due to heating of the heating fluid or water. This phenomenon in common parlance is described as "the hot water being lighter rises to the top and is replaced by cold water from the bottom of the tank".

**Objective**

The objective of this chapter is to look at the method in which the flow of water takes place in a thermo-siphon water heating system. A method for calculating the available head is also being developed.

**Differential head for Thermo-siphon flow**

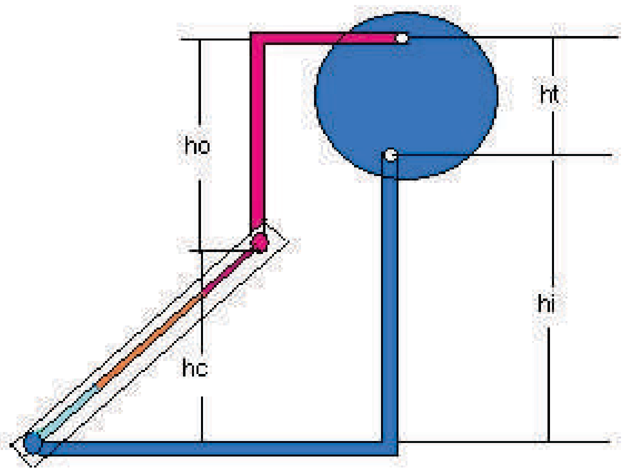
If we start looking in details at the smallest of the thermo-siphon system we find that there are following participants in this heating.

1. Flat plate solar collector where the radiation is received absorbed and converted to heat resulting in heating of the absorber plate. The absorber Plate is connected to the tubes carrying water and transfers the heat to the water inside the tubes. The temperature of water at the bottom end of the collector corresponds to the inlet piping to the solar collector. The temperature of water at the top end of the solar collector corresponds to the outlet temperature of the collector. The density of water in the solar collector can be considered as the density of water at the average of inlet and outlet temperature.

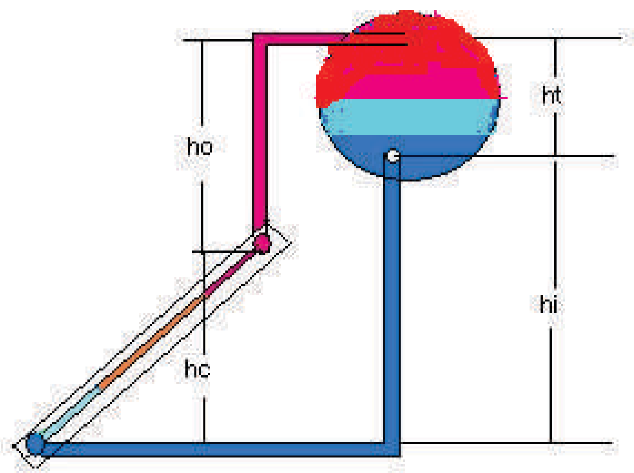
2. Inlet piping connects the solar collector to the bottom of the tank and the water temperature corresponds to temperature at the bottom of the tank. The density of water in this pipe is the density of water at temperature at the bottom of the tank.

3. The outlet piping from the solar collector to the storage tanks connects the solar collector to the storage tank close to the top of the tank. The temperature of water in the pipe is the temperature at the outlet of the solar collector as long as there is flow of water from the collector to the tank.

4. The Storage tank has water at the cold water inlet temperature in the beginning of the heating cycle and as heating continues the top part of the water is replaced by hot water and the level of cold water keeps decreasing during the heating cycle. So the density of water initially is the density of water at cold water inlet temperature and by the end of the heating cycle the density of the water shall be at the designed temperature.

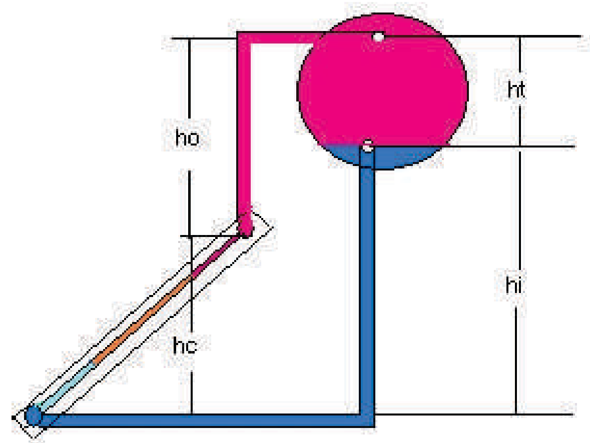



**Condition I:** Beginning of the heating cycle




**Condition II:** At the middle of the heating cycle






**Condition III:** at the end of the heating cycle

If we consider the following

$T_i$ = Cold water inlet temperature

$T_o$ = Hot water out let temperature from the solar collector

$h_c$ = Vertical height of the collector from the inlet to outlet from the collector

$h_i$ = Vertical height of the inlet piping from outlet of tank to inlet of collector in meters

$h_o$ = Vertical height of the outlet piping from the collector to tank inlet in meters

$h_t$ = vertical height of the storage tank from tank inlet to outlet connections to the solar collector in meters

$P_i$ = Specific gravity of water at inlet temperature

$P_o$ = Specific gravity of water at outlet temperature

Then the available thermo-siphon head for flow of water in the solar water heating system can be defined as

$h = h_t \times \rho_i + h_i \times \rho_i - h_c \times (\rho_i + \rho_o)/2 - h_o \times \rho_o$

This will be applicable at the beginning of the heating cycle and will change as the temperatures change due to change in solar intensity and the replacement of cold water with hot water in the storage tank.

Towards the middle of the heating cycle when half of cold water has been replaced with hot water in the storage tank

$$h = h_t x(\rho_i + \rho_o)/2 + h_i x \rho_i - h_c x (\rho_i + \rho_o)/2 - h_o x \rho_o$$

Towards the end of the heating cycle when almost all of cold water has been replaced with hot water in the storage tank

$$h = h_t x(\rho_o) + h_i x \rho_i - h_c x (\rho_i + \rho_o)/2 - h_o x \rho_o$$

The diagrams TS1, TS2 and TS3 show the conditions at these times in the solar water heating system.

The temperatures, efficiency of the collector and the flow rate of water reach a dynamic equilibrium based on the head of water generated and the pressure loss due to flow in the solar collector, connecting piping and velocity head loss due to changes in direction of flow and loss of velocity in the storage tank.

The same principle is applicable for calculation of the thermo-siphon head for larger solar water heating systems except that the data may change based on the configuration.



# Table 10

| Thermosiphonic Head Calculations Initial Heating | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Collector Size | | | Height | 2080 | Width | 1070 | Projection | 45 | |
| Header | Length | 1160 | Diameter | 25.4 | Thickness | 0.71 | ID | 23.98 | |
| Riser | Length | 1970.2 | Diameter | 12.5 | Thickness | 0.5 | Number | 9 | |
| Riser Projection in Header | | | | 2 | | | | | |
| Riser | Angle | Height | Height | Height | Temp | Water | Temp | Water | Differential |
| Header to | Collector | Riser | Header | Tank inlet | collector | Density | Tan k | Density | Head |
| Header | | * | Tank inlet | to outlet | top | at Temp | Bottom | at Temp | water col |
| Mtr | Deg | Mtr | Mtr | Mtr | Deg C | Kg/Cub M | | | mm |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 60 | 983.2 | 20 | 998.2 | 17.62 |
| | | | | | | | | | |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 50 | 988.1 | 20 | 998.2 | 11.86 |
| | | | | | | | | | |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 45 | 990.6 | 20 | 998.2 | 8.93 |
| | | | | | | | | | |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 40 | 992.1 | 20 | 998.2 | 7.16 |
| | | | | | | | | | |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 35 | 994 | 20 | 998.2 | 4.93 |
| | | | | | | | | | |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 30 | 995.7 | 20 | 998.2 | 2.94 |
| | | | | | | | | | |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 60 | 983.2 | 20 | 998.2 | 16.02 |
| | | | | | | | | | |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 50 | 988.1 | 20 | 998.2 | 10.79 |
| | | | | | | | | | |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 45 | 990.6 | 20 | 998.2 | 8.12 |
| | | | | | | | | | |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 40 | 992.1 | 20 | 998.2 | 6.51 |
| | | | | | | | | | |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 35 | 994 | 20 | 998.2 | 4.49 |
| | | | | | | | | | |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 30 | 995.7 | 20 | 998.2 | 2.67 |
| | | | | | | | | | |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 60 | 983.2 | 20 | 998.2 | 13.79 |
| | | | | | | | | | |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 50 | 988.1 | 20 | 998.2 | 9.29 |
| | | | | | | | | | |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 45 | 990.6 | 20 | 998.2 | 6.99 |
| | | | | | | | | | |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 40 | 992.1 | 20 | 998.2 | 5.61 |
| | | | | | | | | | |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 35 | 994 | 20 | 998.2 | 3.86 |
| | | | | | | | | | |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 30 | 995.7 | 20 | 998.2 | 2.30 |

# Design of piping for thermo-siphon systems

**Introduction**

The design of thermo-siphon solar water heating system involves matching the available head for flow to the pressure drop required for maintaining that flow. It is only under such conditions that a thermo-siphon system will provide the desired results. The methods of calculating these have been provided in the earlier chapters

**Objective**

The objective of this chapter is to emphasize that the calculation tools made available for calculating the available head in thermo-siphon system and the pressure drop that takes through various components of the solar water heating system can be used to select optimum size of the pipe required.

The piping to be chosen for the thermo-siphon solar water heating system is to be decided on the available head for the flow at the desired flow rate. Generally it is enough to design the piping based on noon time flow rate to be approximately equal to 20% of the system capacity at the desired temperature at noon time. The thermo-siphon head available in the morning is higher than in the afternoon due to tank having only cold water in the morning. The system efficiency is better in the afternoon due to higher ambient temperature and compensates the loss due to lower velocity of flow due to decreased thermo-siphon head.

The best way is to prepare a layout of solar collectors based on the area available. The layout is to be prepared with not more than 5 collectors connected in direct header to header connection. Then, assume a piping configuration with velocities in the range of 15 centimetre / sec to 50 centimetre / sec through different parts of the system and calculate the friction head and velocity head required for the desired flow rate. If the available head is higher than head for the required flow rate the piping sizes can be decreased and if it is lower than the head required for the desired flow rates piping sizes may have to be increased to achieve the balance. At other times the height of the tank may be increased (to obtain a higher thermo-siphon head).

The calculation sheets show the method used to calculate the pressure drop in collectors and piping.





# Heat Exchanger for thermo-siphon system

**Introduction**

The heat exchanger for thermo-siphon systems are different from the forced flow system for the simple reason that the available hydrostatic head for flow is to be generated by the temperature differential in the fluid stream and this is very small (of the order of few millimeters of water column). The flow must be maintained with this kind of hydrostatic head.

**Objective**

The objective of this chapter is to familiarize the designers with types of the heat exchanger used in thermo-siphon water heating system. The tools for calculating the heat transfer area of the heat exchanger have also been explained with examples.

**Heat Exchanger design for thermo-siphon systems**

Following designs have been adopted for this purpose.

1. Jacket type heat exchanger

In this heat exchanger the heating fluid flows from the solar collector to jacket around the storage tank and returns back to solar collector after transferring heat to water in the storage tank. The design is quite useful and has been used extensively throughout the world for very small systems and in our country for smaller to medium size systems.

The design has at times resulted in tank failure under external pressure when the collector fluid is allowed to have high pressure causing failure of the storage tank under external pressure.

2. Tubular design for thermo-siphon heat exchanger

This design utilizes multiple tubes connected in parallel configuration with an inlet header and outlet header arranged to obtain smooth flow passages to have minimal pressure drop in the flow. The heat exchanger is placed inside the tank and heat exchange is between the fluid flowing through the heat exchanger tubes and the water contained in the hot water storage tank.

3. Coil type heat exchanger

This type of heat exchanger can also be used for thermo-siphon system if the design is carried out in such a manner as to ensure flow with the available hydrostatic head in thermo-siphon system.

The natural circulation type heat exchangers use the following method for calculating the heat transfer coefficient for the heat exchange between the inside of the jacket and the hot water tank side.

**Natural Convection**

$$T_M = \frac{1}{2}\left(T_w + T_\infty\right)$$

All properties at mean temperature

$$\mathrm{Gr} = \frac{L^3 \cdot g \cdot \rho^2 \cdot \beta \cdot \left|T_w - T_\infty\right|}{\mu^2}$$

$$\mathrm{Nu} = \frac{h \cdot L}{k}$$

L = characteristic length (see below)

| | Nu₀ | "Length" L |
|---|---|---|
| Vertical wall | 0.67 | H |
| Horizontal cylinder | 0.36 | D |
| Sphere | 2.00 | D |

For ideal gases: $\beta = \frac{1}{T_M}$ (temperature in K)

$$\sqrt{\mathrm{Nu}} = \sqrt{\mathrm{Nu}_o} + \left[\frac{\frac{\mathrm{Gr} \cdot \mathrm{Pr}}{300}}{\left(1 + \left(\frac{0.5}{\mathrm{Pr}}\right)^{9/16}\right)^{16/9}}\right]^{1/6}$$

Churchill, Thelen)

valid for 10-4 < Gr Pr < 4•1014,

0.022 < Pr < 7640, and constant wall temperature

Tw is temperature at the wall and tw is temperature away from the wall and all properties of the fluid are taken at mean temperature Tm



Gr = Greshoff number

e = Density of the fluid in Kg/m³

β = Volume metric expansion coefficient of fluid at Tm

Nu = Nusset number

Pr = Prandtl Number

h = heat transfer coefficient

k = thermal conductivity of the fluid

# Table 11

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| System Size | 500 | | | | | | |
| | | | | | | | |
| | | | Tube Dia | 0.0254 | | | |
| | | | Thickness | 0.0016 | | | |
| | | | Tank side Water | | | Collector side water | |
| T tank inlet | 20 | °C | hc | | | hh | |
| | | | | | | | |
| T tank top | 60 | °C | water properties | | | water properties | |
| | | | at avg temp | | | at avg temp | |
| | | | | | | | |
| T collect oulet | 70 | °C | **40** | | | **50** | |
| | | | | | | | |
| T collect inlet | 30 | °C | P | 992.3 | | P | 986 |
| | | | | | | | |
| Flow collector | 100 | LPH | µ | 6.50E-04 | | µ | 5.04E-04 |
| | | | v | 6.59E-07 | m²/sec | v | 5.56E-07 |
| Q | 4000 | Kcal | Pr | 4.31 | | Pr | 3.54 |
| | 4648 | W | K | 0.634 | | K | 0.648 |
| | | | b | 0.000387 | Unit | b | 0.000449 |
| | | | | | | | |
| For Counter flow | | | | Meter | | Dh | 0.0222 mm |
| | | | | | | | |
| 1 | 10 | | Gr | 7.16E+05 | m/sec | Vm | 0.07 m/sec |
| | | | | | | | |
| 2 | 10 | | **Nuo** | 0.36 | | Re | 2.86E+03 |
| | | | | | | | |
| m | 10 | | Nu | 24.18 | | Nu | 2.22E+01 |
| | | | | | | | |
| | | | ho | 603.53 | | **hh** | **649.01** |
| | | | | | | | |
| | | | f | 0.0005 | | | |
| | | | | | | | |
| | | | h | 255.11 | | | |
| | | | | | | | |
| | | | **A** | 1.82 | m² | | |
| | | | | 22.83 | Meter | | |
| | Coil pressure | | | | | | |
| | drop | | | | | | |
| | Tube Flow | Re | 8680 | | | | |
| | | f | 0.032 | | | | |
| | | Length | 22.83 | | | | |
| | | V | 0.07 | | | | |
| | Pressure Drop | ?P | 8.6365 | mm water | | | |
| | Velocity head | | 0.262 | mm water | | | |

# Table 12

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Heat Exchanger | 100 | | | | | | | | | | | |
| Tank Horizontal | | | | | | | | | | | | |
| Tank of Dia | 0.39 | | | | Tank | | 0.39 | | | Equvalent | | 0.038261 |
| Dia of jacket | 0.41 | Length | 0.22 | | dia | | | | | dia | | |
| | | | | | Tank side Water | | | Collector side water | | | | |
| Cold Inlet to Tank | Tci | 20 | °C | | hc | | | hh | | | | |
| Hot outlet from tank | Tce | 60 | °C | | water properties | water properties | | | | | | |
| | | | | | at avg temp | at avg temp | | | | | | |
| inlet to H.E. | Thi | 70 | °C | | 40 | | | 50 | | | | |
| Cold return to Collectors | The | 30 | °C | | ρ | 992.2 | | ρ | | 988.1 | | |
| | | | | | μ | 0.000653 | | μ | | 0.648 | | |
| Flow through H.E. | mh | 20 | LPH | Kinematic viscosity | √ | 6.59E-07 | | √ | | 6.56E-07 | | |
| Heat Load | Q | 800 | Kcal | | Pr | 4.31 | | Pr | | 3.54 | | |
| | | 929.6 | W | thermal conductivity | K | 0.634 | | K | | 0.648 | | |
| | | | | Volumetric Coefficient | b | 0.000387 | | b | | 0.000449 | | |
| | For Counter flow | | | Tank diameter | Dh | 0.39 | | Dh | | 0.038261 | | |
| | □1 | 10 | | Velocity | Vm | Vm | | 0.002525 | | | | |
| | □2 | 10 | | Reynolds No. | Re | | | Re | | | | |
| LMTD | □m | 10 | | Grasoff no | Gr | 1.04E+10 | | Gr | | 1.15E+07 | | |
| | | | | Nusset No initial | **Nuo** | **0.36** | | **Nuo** | | **0.36** | | |
| | | | | Nusset No | Nu | 480.22 | | Nu | | 51.56 | | |
| | | | | | | | | | | | | |
| | | | | heat transfer coeffient | ho | 780.67 | | hi | | 873.28 | | |
| | | | | Fouling Factor | f | 0.0005 | | | | | | |
| | | | | | h | 341.7562362 | | | | | | |
| | | | | | | | | | | | | |
| | | | | Heat transfer Area | **A** | **0.27** | | | | | | |
| | | | | | | | | | | | | |
| | | | | Jacket length required | 0.22 | | | | | | | |





# Examples of some thermo-siphon systems

## Introduction

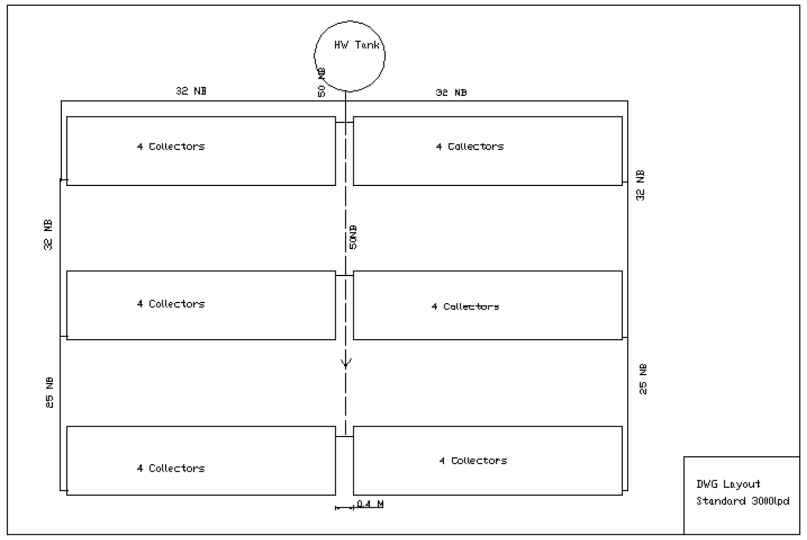
The use of thermo-siphon systems for systems of large capacity is quite unique to our country. It was taken up mainly to ensure reliability of the solar water heating systems in early nineties due to regular failure of the pumps and controls of the solar water heating systems. The situation has improved since then due availability of better pumps and controls, but the use is still persisting due to independence of system performance on power supply.

## Objective

The objective of this chapter is to familarise the designers with the kind of thermo-siphon systems which have been installed and working effectively for some time and to create awareness that with the design tools being made available, they can make use of these systems to provide users independence from power supply availability and the voltage fluctuations. Also due to absence of prime movers and controls these systems provide better reliability.Thermo-siphon solar water heating systems are extensively being used in the country.  Initially, use of thermo-siphon systems was started for domestic applications up to three collector systems. Also only direct heating systems were used. Heat Exchanger for these solar water heating systems were developed in the year 1989-90 and use of indirectly heated solar water heating systems was started for areas where freezing was a problem due to extremely low night temperatures.

However, at number of places the problem of hard water were noticed which created clogging of the solar collector tubes and use of heat exchanger based thermo-siphon systems was extended for solar water heating systems used with hard water. With time the application of thermo-siphon type solar water heating systems has been extended to solar water heating system of capacity of up to 10000 liters per day. In the examples of the existing solar water heating system design the following solar water heating systems are being considered.

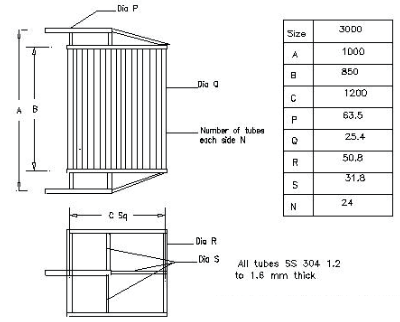
1. A typical solar water heating system of 3000 lpd capacity with 24 solar flat plate collectors with orientation at 25 degree to horizontal without heat exchanger




2. A typical solar water heating system of 3000 lpd capacity with 24 solar flat plate collectors with orientation at 25 degree to horizontal with heat exchanger will have the similar configuration except the use of a heat exchanger inside the tank. The system will also have an expansion/make up tank to allow for expansion of heating fluid when heating takes place during the day period and make up when the fluid in the primary collector circuit contracts with cooling in the night.

The design of heat exchanger used in these cases may be jacket type or a cage type configuration as shown in attached sketch



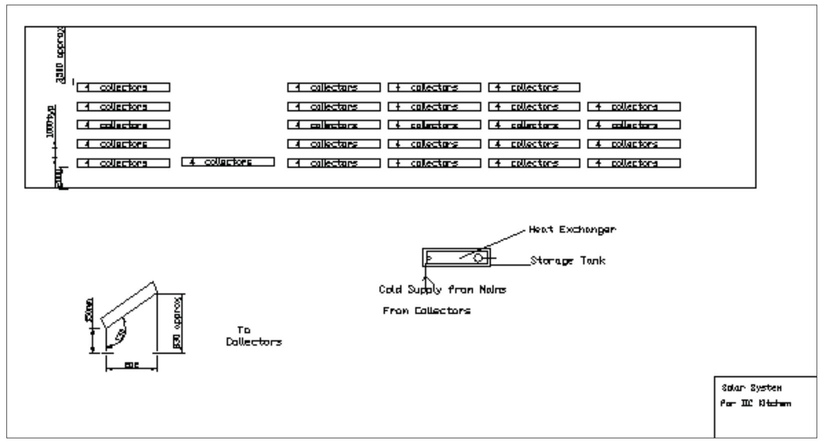


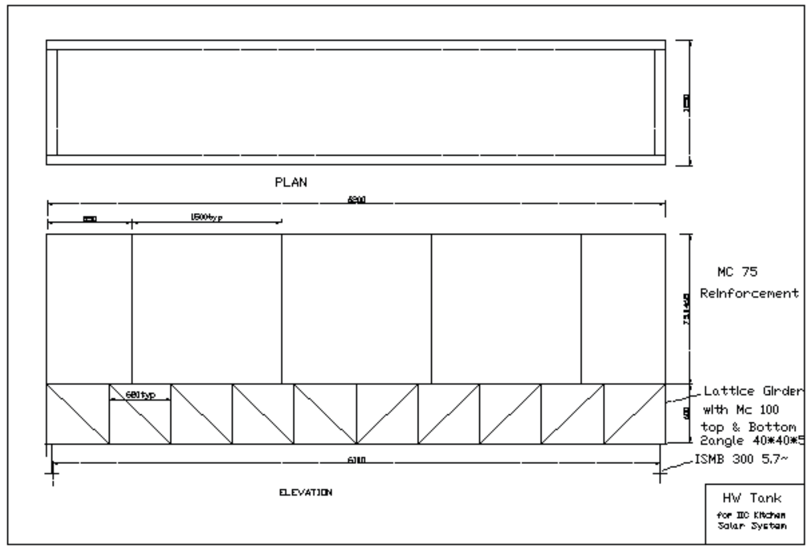

Heat Exchanger Thermosiphon 3000 lpd

3. Details of 10000 Liter per day capacity solar water heating system with heat exchanger with collectors installed at lower level with the hot water tank and heat exchanger installed at 30 meters above the collector level. The Solar Water Heating System was Installed in 1997 at AP Bhavan New Delhi

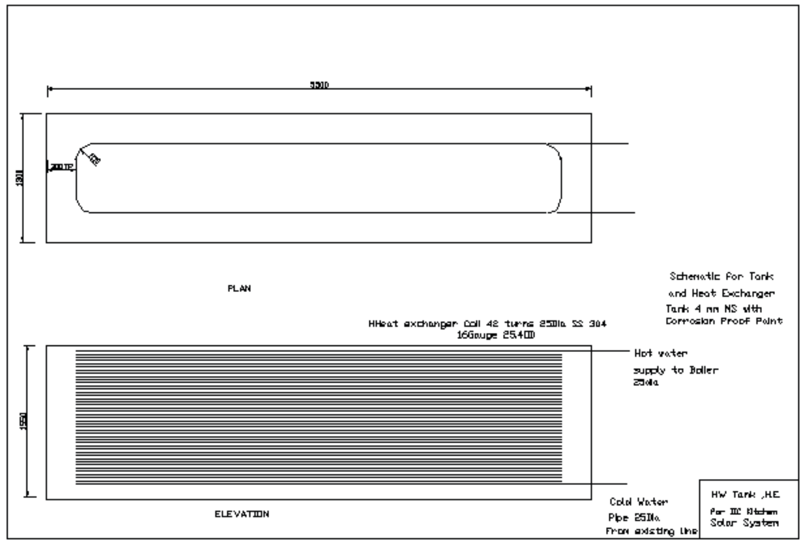
4. Details of 10000 Liter per day solar water heating system with low height collectors and storage tank installed marginally above the collector height. The heat exchanger in this case is provided so that pressurized water can flow through the heat exchanger without the need for a pressurized tank, Solar Water Heating System was Installed in 2002 at IIC New Delhi

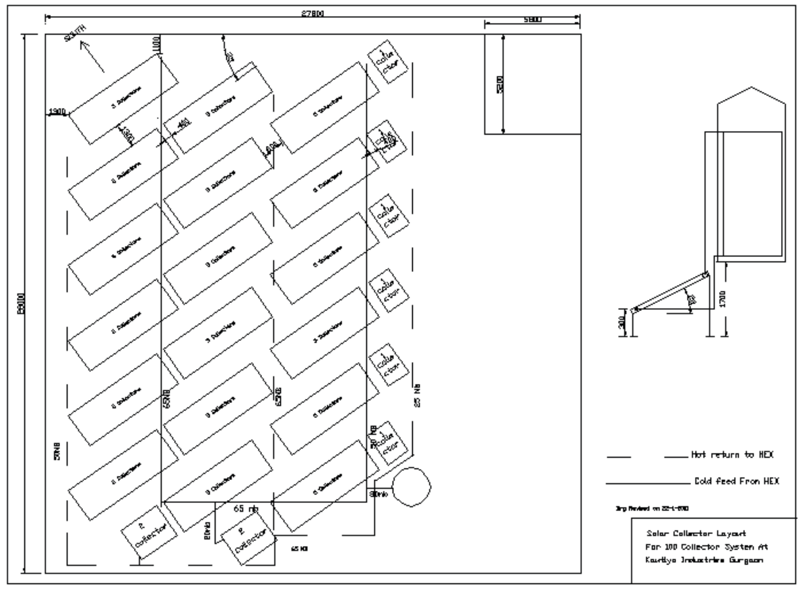
These examples give the idea of the versatility in design that is possible in solar water heating systems designed on thermo-siphon basis.






10000 litres per day capacity system at Kautilya Industries, Gurgaon with Heat Exchanger

Chapter 22

# Examples of some forced flow systems

**Introduction**

In the earlier chapter on examples of thermo-siphon system design were explained and how these have been used to improve reliability was emphasized. The forced flow solar water heating systems are more efficient as these use high flow velocities of water.

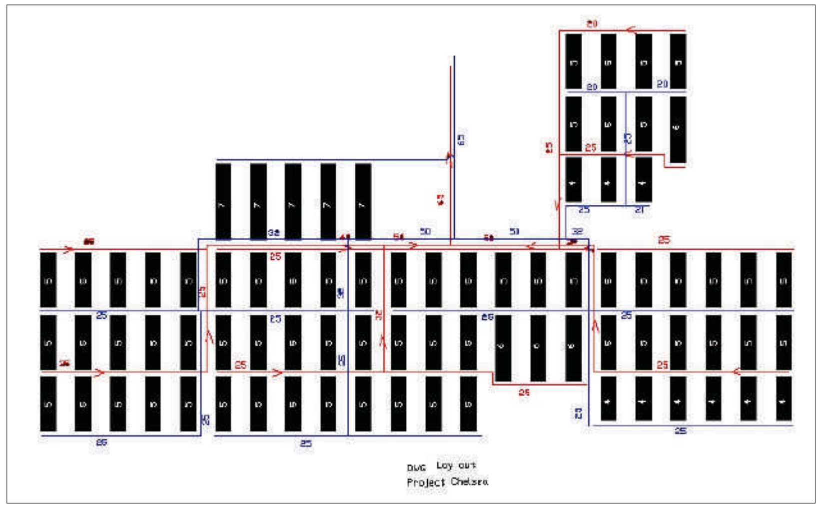
**Objective**

The objective of this chapter is bring to the attention of the designers the importance of designing in detail the various components of the solar water heating system to ensure trouble free performance.

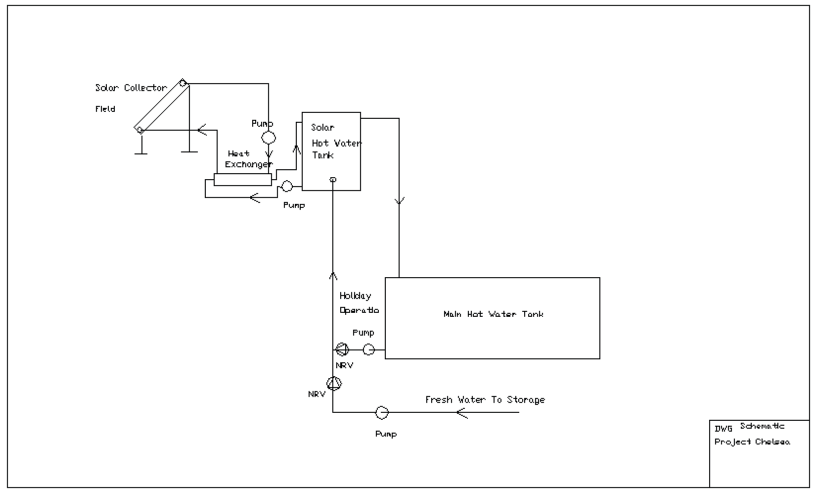
The solar water heating systems with pumps as prime movers for the water flow have been installed since 1975 in the country and there are number of typical designs which have used. Some of the systems installed in early 1982-83 are still functional and some which were installed much later have also become problematic. Some had basic flaws in the design of the solar water heating systems and some systems were built without consideration to designing of the components and were expected to perform with the help of adjustments to be done with the help of flow adjustments with flow measuring devices in place.

**Following are the examples of some of the solar water heating systems with forced flow systems**

1. Solar water heating systems with all collector in parallel with heat exchanger

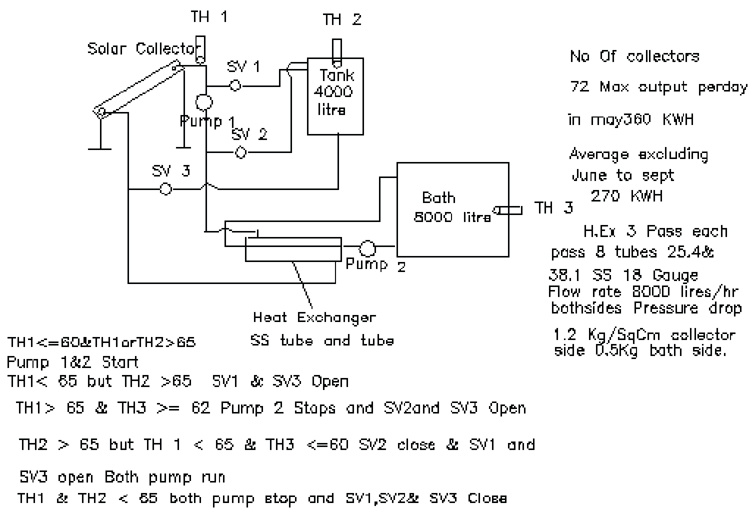







25 Lakh Kcal perday system at Chelsea Jeans Manesar in Haryana

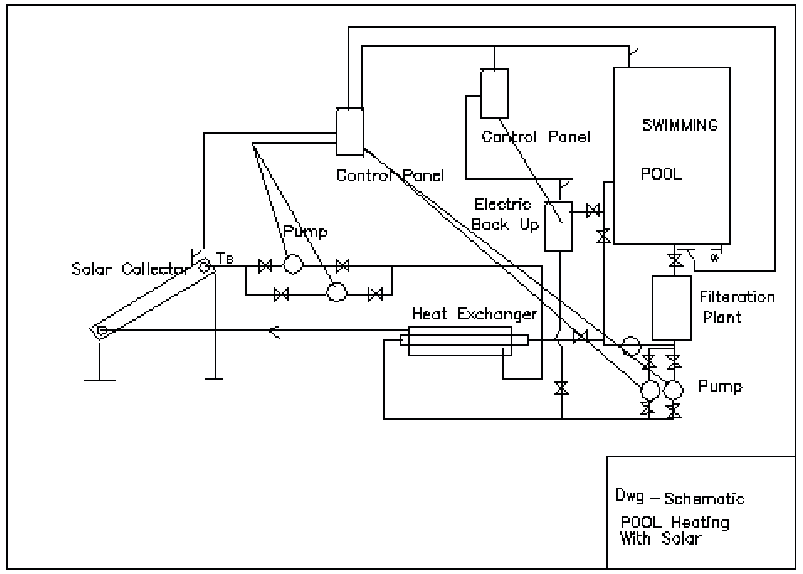
1.Solar water heating systems for Electroplating Bath Heating




12 Lakh Kcal per day system for Nickle Bath at Kangaroo Industry Ludhiana



2. Solar water heating system for Swimming Pool Heating



# Various applications of solar water heating systems and how design parameters are determined for various applications

**Introduction**

In the previous chapters we have discussed the techniques of designing the components of the solar water heating systems which are simply used to provide hot water for use in domestic or commercial applications for supply of hot water. The use of solar water heating system is not limited to providing hot water for bathing or kitchen applications. The solar water heating systems can also be used to meet the requirement of various industrial processes to meet the requirement of heat at low temperatures.

**Objective**

The objective of this chapter is to improve understanding of the other applications so that design tools developed so far can be made use of for the other applications of the solar water heating systems also.

**Applications of solar water heating systems**

The requirement of the processes and time of use of the thermal energy become the guiding principle for design of the solar water heating systems.

We shall discuss a few examples of these requirements and how the design parameters are specified

1. Solar water Heating systems for Swimming Pool Heating

The requirement of pool heating are in the range of 25-30 deg C and in some cases for medical therapy reasons at 36 -38 Deg C. The swimming pool has a huge quantity of water and the solar water heating system only provides the daily loss that happens due to following reasons

a) Evaporation of water from the pool surface during use and when it is not covered.

b) Convection loss to the atmosphere when air is moving over the pool surface at low temperature

c) Heat loss due to conduction to surrounding earth or structures.

d) Radiation loss from the surface of the pool.

All these losses may bring down the temperature of the pool by 0.5 to 2 degree in day and over a number of days the pool temperature may drop by few degrees in winter months to make it unsuitable for use. The solar water heating system for the pool has to add heat to maintain temperature of 25-30$^{0}$ C .The water may not be suitable for direct use in solar collectors. A heat exchanger is to be provided for that purpose. There is no storage of heat required as the pool itself has huge storage capacity. The heat exchanger must work at 5-10$^{0}$ C differential so that the collector efficiency is at the highest level. This requirement will decide the flow rate in the collector side as well as the pool side of the heat exchanger and the requirements of heat transfer area.

2. Solar water heating system for meeting boiler feed water requirements

Some of the boilers cannot use economizers and are not having adequate condensate recovery systems due to the process limitations. In these cases use of hot water from the solar water heating system can result in substantial saving of fuel. The requirement may be only during the day period. In this case only a small storage may be required. Boiler feed water will be useful in the range of 80-90 $^{0}$C. The solar water heating system must be designed to meet these requirements

3. Solar water heating system required in industry at fixed temperature for processes.

In some of the industries the water is required at fixed temperature and at certain intervals. The solar water heating system must be designed to meet these requirements with provision of storages calculated to meet these requirements. Some of these industries have a weekly day off. It will be desirable to have storage of heat so that the solar heating capacity is available for use for the rest of the week.

4. Solar water heating system required to maintain the temperature of electroplating baths or degreasing/ cleaning baths for metal processing. These systems are similar to pool heating but the temperature is much higher and there will be difference in availability and generation of heat from the solar system. Some kind of buffer storage is required to meet the demand in low availability period and to add to storage in high availability period. The details of buffer storage tank need to be worked out and also a method of shifting from use to storage and from storage needs to be established.

Chapter 24

# Installation requirements for solar water heating systems

**Introduction**

The solar system installations are limited by the conditions at site of installation. This imposes limitations on the design and installation of the solar system. Solar energy is a distributed form of energy and it needs to be collected from a large area depending on the requirement.

**Objective**

This chapter is intended to look into the limitations and also to discuss some solutions which have been attempted in the some installations. This is also intended to spur he designers and installers of solar systems to think beyond the obvious solutions and look at other possibilities as some other people have done

**Installation Requirements**

The requirement of area can be worked out from the amount of water required and the required temperature. Also in the process of optimizing the energy collection the solar collectors need to be installed at an orientation facing south. The rows of solar collector need to be spaced so that the shadow of one row collectors does not affect the next row of collectors. Also the other structure or trees may create shadows on the available area. All the structures which are in the range of 45 degrees to the east and west of the collectors array are to be examined for their effect on the collectors. Some unique ways of meeting the area requirement have been developed and are shown in illustrations.

For thermo-siphon systems the overhead tank has to be higher than the top of the hot water storage tank to ensure flow of hot water from the top of the tank.

The area of installation must have access for installation as well as for regular cleaning of the solar collectors and other maintenance requirements. For storage tanks to be placed on top of buildings the buildings must be capable of sustaining the load of the storage tank and the supporting structure.

The cold water supply must be regularly available and quality of water must be known to design the system according to the water quality.

The demand pattern of water, if known, may help in optimizing the storage capacity and also the backup system capacity. If the solar water heating system is being retrofitted to an existing system with a boiler or hot water generator the method of integrating the solar water heating systems with the existing system must be established.



The supply piping must not be too large in diameter and length. In case it is absolutely necessary to have large diameter piping and long lengths of pipe in distribution system, a controlled way of re-circulating water is to be developed to avoid wastage of water.

Solar Collector installed on South Facing Roof on structure supports inclined to get more effective Area

Collectors Installed in two in Inclined Plain South Facing to avoid shadows at Aurbindo Ashram New Delhi

# Supports for solar collectors

**Introduction**

Solar systems are outdoor installations and are subjected to vagaries of nature and must have this accounted for in the installation. There have been installations where solar collector have been toppled and or displaced by wind. The supporting and anchoring of supports to the surface below and collectors has to be ensured.

**Objective**

The objective of this chapter is to remind the designers and installers of importance collector supports play in the solar water heating system and what is demanded from these supports.

**Supports for solar collector have to meet the following requirements:**

1. The solar collectors are oriented and placed in the right direction.
2. The solar collectors are attached to the support as to avoid any toppling of the solar collector with wind or any physical pressure.
3. The supports are attached to the ground or structure so that it can sustain the highest anticipated wind velocity without damage to the collectors.
4. In case solar collectors are installed on an inclined roof these must be attached to the roof so that no sliding of the collectors is possible.
5. The design of supports is to be carried out by considering the load of the filled collectors and the wind load on the collectors in extreme wind conditions
6. The anchoring of the supports to the ground or roof structure must take into account the wind load on the solar collectors.
7. Where anchoring to roof is not possible the longer legs of the supports may have dead weight anchoring in the form a concrete block cast around the leg.
8. The supports are exposed to rain and sun and temperature cycling and it shall be necessary to protect these from corrosion due to rain water. The protection must be such that it can last for long time in these conditions. The hot dip galvanized supports are the best option in these conditions.





# Supports for storage tanks and heat exchangers

**Introduction**

Just as in case of solar collectors the storage tanks and heat exchangers and other components are also to be located and anchored to the surface where these are placed. The tanks are also heavy when filled with water.

**Objective**

The objective of this chapter is to define the design and installation requirement for the supports of the tanks and heat exchangers.

**Various aspects to be considered in design and installation of tanks and heat exchangers:**

1. The hot water storage tanks need to be placed near the collectors at level higher than the top of the solar collectors in thermo-siphon solar water heating systems.
2. This creates a requirement for a support structure which will maintain the level of the storage tank.
3. The supports must be designed to hold the weight of the hot water storage tank in filled conditions.
4. The supports are generally designed as frame structures with redundant members to provide rigidity to the structure.
5. The transfer of load of tank from support to building structure is to be considered in the design of the structure and in case of large tanks specific approval must be obtained from building structural consultants regarding the load bearing capacity. Ways may be found of transferring the load to building columns and beams or load bearing walls.
6. The stresses caused by the structure on the body of the tank in the transfer of load to the structure must be accounted for in the design of the tank.
7. The stability of the tank under and the structure against toppling due to wind load or any other disturbance such as earth quake conditions must be considered.
8. Hot water tanks in forced flow solar water heating systems may be placed at lower level than the solar collectors and may have lesser problems of rigidity and stability.
9. Sometimes separate cold water tanks are required to be installed for providing cold

water supply exclusively to the hot water tanks in thermo-siphon systems. Usually plastic tanks are used. These tanks have additional requirement of needing continuous support at the bottom of the tank. Also, if placed on the roof level, these cold water tanks must be properly restrained to avoid toppling and falling down with wind when empty. This restraint must also take care of earth quake loading on the tank in filled conditions.





# Piping connections, fittings and valves for solar systems

**Introduction**

A solar water system is not complete till the connecting piping, fittings and valves have been installed. Even when designing has been done carefully to ensure good performance of the solar water heating system, it is essential to take of some other essential points in the installation of the pipes, fittings and valves.

**Objective**

The objective of this chapter is to look at some the factors to be considered for proper installation of the connecting piping, fittings and valves.

**Some of the common features are given below but the list is not final and more may emerge:**

1. In smaller thermo-siphon solar water heating systems having up to 3 to 4 solar collectors, the piping connections have been replaced with EPDM hose connections. These are easy to install but have significant heat loss as these are not insulated.
2. All other solar water heating systems are being used with galvanized pipe connections. Some new high temperature plastic pipes such as KITEC composite pipes, CPVC etc. are also being used for the solar water heating system piping connections.
3. At times, it is seen that the piping connections in thermo-siphon systems are not made properly resulting in air locking of the flow. The piping connections in these systems should be done in a manner that the level of the pipe is either rising when moving from collector to the storage tank or the level is maintained. If the level of the pipe drops and rises again, it will result in the air bubble being trapped in the pipe and blocking the thermo-siphon flow.
4. Even in case of forced flow systems if piping is done in a manner where there is no escape for air bubbles formed, it shall result in unequal flows in parallel paths and some of the parallel paths in a large system may have low flows and high temperatures. The solar water heating system may not work efficiently in these conditions.
5. The pipe fittings must be of a quality corresponding to the pipe and compatible with the pipe.
6. The pipe lines must be supported at regular intervals so that the load of these is not

transferred on to collector headers or tank connections.

7. Use of valves is required for isolating sections or parts of the solar water heating system for maintenance. However, valves themselves have a requirement of maintenance and use of too many valves may actually add to maintenance requirements rather than easing maintenance. Also valves used are with brass or gun metal material and these at times contribute to galvanic corrosion in piping near the threaded joints where the zinc has been removed in process of cutting threads.

8. Quite often use of non return valves is made in the cold water supply lines to the hot water storage tanks. This at times result in pressurizing the hot water tanks if the tank is not vented or is vented with an air release valve. This is caused by expansion of water with heating.

9. Non return valves are required on the discharge side of the pumps to protect the pump when the pump stops.





# Insulation of Pipes, Tanks and Heat Exchangers

**Introduction**

The solar water heating systems are designed to collect the heat of the sun and provide hot water. This heat collected however can be lost in various ways in its passage from the solar collector to the storage tank and beyond to the use point. The insulation plays a crucial role in limiting these losses so that the solar water system may effectively deliver the hot water

**Objective**

The objective of this chapter is to emphasize the importance of insulation and nature of requirements for the insulation.

**Various aspects to be considered for insulation:**

1. Insulation of the pipes, hot water storage tanks, and external heat exchangers is required to retain the heat which has been collected by the solar collectors in a solar water heating system.
2. The components of the solar water heating systems are most of the placed in open air exposed to rain water and sunshine.
3. The insulation to be used must provide good insulation characteristics and must be protected from the environmental conditions.
4. All pipes whether plastic or metal require insulation.
5. Pipes embedded in walls or ceilings require insulation more than pipes in air as these are intimate contact with the solid building elements which will act as heat sink for these pipes.
6. Insulation characteristics of solid materials even ceramics is poorer than the foam or fibrous materials.
7. The fibrous materials however have limitations when used in walls and ceiling during construction period as these absorb water used in construction which may be retained for a long time. Closed cell foam materials which are impervious to water are more suited for this purpose.
8. The insulation thicknesses must be worked out to reduce the heat losses to minimal levels.
9. The insulation need to be retained in shape by retaining materials and also protected

from water ingress during rains by cladding materials.

10. The external cladding used must be suitable to retain shape and not get damaged under exposure to environment. Hot dipped GI sheets have better shape retention as compared to aluminum sheets as cladding material. Thin aluminum sheets also tend to develop holes under bird droppings.
11. The cladding is to be done in a manner that there is no ingress of water through joints in cladding material.
12. Use of closed cell materials and preformed sections of insulation perform better due to lesser probability of water seeping through the insulation.



Chapter 29

# Estimating Heat Losses from Piping and Tanks

**Introduction**

The use of insulation helps in reducing the heat losses from the piping, tanks and heat exchangers. However these losses are still significant and need to be calculated. The calculations are needed to understand the role of insulation in utilization of the solar water heating system.

**Objective**

The objective of this chapter is to look in quantitative terms at heat losses from various components. This also will help in deciding the extra capacity required to meet these losses. Also it will help in balancing the effectiveness by improving insulation or by adding extra capacity to meet requirements.

Calculations of heat losses from different components-

Heat losses from cylindrical tanks with flat or dished ends

The heat losses from the insulated tanks are determined from the following parameters

$T_i$- temperature of water inside the tank on average basis

$T_a$- temperature of ambient air

t - Thickness of insulation at the circumference and at the sides in meters

k - Conductivity of the insulation material in W/Hr/m/K

$h_w$ – Film coefficient of heat transfer on water side in the tank in W/Hr/$m^2$/K

$h_a$- Film coefficient of heat transfer in the ambient air side W/Hr/$m^2$/K

d the inside diameter of the tank in meters

dins The outside diameter of the insulation material in meters

L = length of the tank in meters

The conductive heat transfer through the circumference of insulation is determined by the formula

$$Qcc= 2\pi kL(T_i - T_a)/(\log_n(dins/d)) \text{ in watts}$$

The heat loss through the ends is determined

$Q_{ce} = \pi d^2 (T_i - T_a) k / 4t$ in watts

To account for hw the film coefficient of heat transfer inside the tank and ha the film coefficient of outside air

The circumferential heat transfer coefficient Uc is determined as below

$U_c = 1/(1/hw + d \ (dins/d)/k + d/(dins\ ha))$ in W/Hr/m2/K

The cylindrical portion of the ends the Ue is determined by

$U_e = 1/(1/hw + t/k + d/dins\ ha)$ W/Hr/m2/K

And the heat losses are determined as below

Heat loss Qc through circumference

$Q_c = U_c \pi d^2 L(T_i - T_a)$ in Watts

Heat loss through ends

$Q_e = \pi d^2 L (T_i - T_a)/2$ in watts

The hourly heat loss from the storage tank

$Q = Q_c + Q_e$

If V is volume of water in the tank in litres and considering specific heat and specific gravity of of water as 1 for all practical purposes

The temperature drop in the tank per hour

T hourly drop = 0.858 Q/V

If the temperatures are considered on daily average basis, then expected temperature drop in a day is

T daily drop = 24xT hourly drop

The heat losses through cylindrical pipes can be calculated in a similar manner by considering only the circumferential loss.

Some typical calculations are enclosed for reference.

The calculations however show that with the amount of insulation normally used the water in distribution pipes or inter connecting pipes will lose practically all the temperature and reach near the ambient in 24 hours. This temperature will be reached sooner for the smaller diameter pipes due to unfavorable surface to volume ratio. The total heat loss from a meter of larger diameter pipe is higher.

Combined with fact that larger diameter pipes have larger volumes the water contained in these pipes may have to be drained or re-circulated to ensure hot water reaching the use point after prolonged gap in usage. The design of piping must be done to account for these losses.



# Table 13

| Calculation of Heat Loss from Tank based on conductive loss with PUF Insulation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| metal resistance ignored | | | | | | | | |
| Water Side Film coefficient | W/m sq/degc | 900 | | | | | | |
| Air side Film Coefficient | W/m sq/degc | 7 | | | | | | |
| Tank Capacity | Litres | 100 | 200 | 250 | 500 | 1000 | 2000 | 5000 |
| Diameter of Tank | M | 0.39 | 0.52 | 0.52 | 0.71 | 1 | 1.2 | 1.6 |
| Length | M | 1 | 1.07 | 1.18 | 1.25 | 1.28 | 1.8 | 2.5 |
| Thickness | M | 0.04 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 |
| k | Watt/m/k | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 |
| Dia ext | M | 0.47 | 0.6 | 0.6 | 0.81 | 1.1 | 1.3 | 1.7 |
| Initial | | | | | | | | |
| Inside Temperature Average | Deg C | 55 | 55 | 55 | 55 | 55 | 55 | 55 |
| Ambient Temperature Average | Deg C | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Heat Transfer Coefficient cicumferential | | 0.63 | 0.62 | 0.62 | 0.50 | 0.49 | 0.49 | 0.48 |
| Heat Transfer Coefficient End | | 0.58 | 0.58 | 0.58 | 0.47 | 0.47 | 0.47 | 0.47 |
| Heat Loss Circumference | Watts | 31.12 | 43.34 | 47.80 | 55.83 | 78.96 | 132.15 | 242.18 |
| Heat Loss End | Watts | 5.56 | 9.85 | 9.85 | 14.90 | 29.49 | 42.42 | 75.32 |
| Total Heat Loss | Watts | 36.67 | 53.19 | 57.65 | 70.73 | 108.44 | 174.57 | 317.50 |
| Total Heat Loss | Kcal/hr | 31.47 | 45.64 | 49.46 | 60.69 | 93.04 | 149.78 | 272.41 |
| Total Heat Loss | Kcal/Day | 755.19 | 1095.34 | 1187.09 | 1456.48 | 2233.04 | 3594.69 | 6537.94 |
| Temperature drop in 1hr | Deg C | 0.31 | 0.23 | 0.20 | 0.12 | 0.09 | 0.07 | 0.05 |
| Temperature drop in 24hrs | Deg C | 7.55 | 5.48 | 4.75 | 2.91 | 2.23 | 1.80 | 1.31 |

# Table 14

| Calculation of Heat Loss from Tank based on conductive loss with Rockwool Insulation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| metal resistance ignored | | | | | | | | |
| Water Side Film coefficient | W/m sq/degc | 900 | | | | | | |
| Air side Film Coefficient | W/m sq/degc | 7 | | | | | | |
| Tank Capacity | Litres | 100 | 200 | 250 | 500 | 1000 | 2000 | 5000 |
| Diameter of Tank | M | 0.39 | 0.52 | 0.52 | 0.71 | 1 | 1.2 | 1.6 |
| Length | M | 1 | 1.07 | 1.18 | 1.25 | 1.28 | 1.8 | 2.5 |
| Thickness | M | 0.075 | 0.075 | 0.075 | 0.1 | 0.1 | 0.1 | 0.1 |
| k | Watt/m/k | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| Dia ext | M | 0.54 | 0.67 | 0.67 | 0.91 | 1.2 | 1.4 | 1.8 |
| Initial | | | | | | | | |
| Inside Temperature Average | Deg C | 55 | 55 | 55 | 55 | 55 | 55 | 55 |
| Ambient Temperature Average | Deg C | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Heat Transfer Coefficient cicumfrential | | 0.59 | 0.57 | 0.57 | 0.43 | 0.42 | 0.41 | 0.40 |
| Heat Transfer Coefficient End | | 0.51 | 0.50 | 0.50 | 0.38 | 0.38 | 0.38 | 0.38 |
| Heat Loss Circumference | Watts | 28.99 | 39.74 | 43.83 | 48.17 | 67.04 | 111.43 | 202.38 |
| Heat Loss End | Watts | 4.83 | 9.15 | 10.09 | 15.15 | 30.69 | 62.08 | 153.01 |
| Total Heat Loss | Watts | 33.82 | 48.89 | 53.92 | 63.33 | 97.74 | 173.51 | 355.39 |
| Total Heat Loss | Kcal/hr | 29.01 | 41.95 | 46.26 | 54.33 | 83.86 | 148.87 | 304.92 |
| Total Heat Loss | Kcal/Day | 696.33 | 1006.73 | 1110.23 | 1304.02 | 2012.63 | 3572.93 | 7318.14 |
| Temperature drop in 1hr | Deg C | 0.29 | 0.21 | 0.19 | 0.11 | 0.08 | 0.07 | 0.06 |
| Temperature drop in 24hrs | Deg C | 6.96 | 5.03 | 4.44 | 2.61 | 2.01 | 1.79 | 1.46 |

# Table 15

| Calculation of Heat Loss From Pipes Based on conductive loss with PUF insulation | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| metal resistance ignored | | | | | | | | | |
| Water Side Film coefficient | W/m sq/degc | 900 | | | | | | | Rubber |
| Air side Film Coefficient | W/m sq/degc | 7 | | | | | | | Hose |
| Pipe Nominal Dia | mm | 15 | 20 | 25 | 32 | 40 | 50 | 65 | 25 |
| Thickness medium Class | mm | 2.65 | 2.65 | 3.25 | 3.25 | 3.25 | 3.65 | 3.65 | 5 |
| Inside Diameter | mm | 0.016 | 0.0216 | 0.0272 | 0.0359 | 0.0418 | 0.053 | 0.0688 | 0.02 |
| Volume | Litre/Meter | 0.20 | 0.37 | 0.58 | 1.01 | 1.37 | 2.21 | 3.72 | 0.31 |
| Diameter of Pipe Externnal | M | 0.0213 | 0.0269 | 0.0337 | 0.0424 | 0.0483 | 0.0603 | 0.0761 | 0.03 |
| Length | M | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Thickness | M | **0.014** | **0.025** | **0.025** | **0.025** | **0.025** | **0.025** | **0.025** | **0.005** |
| k | Watt/m/k | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.025 | 0.25 |
| Dia ext of insulation | M | 0.0493 | 0.0769 | 0.0837 | 0.0924 | 0.0983 | 0.1103 | 0.1261 | 0.03 |
| Initial | | | | | | | | | |
| Inside Temperature Average | Deg C | 55 | 55 | 55 | 55 | 55 | 55 | 55 | 55 |
| Ambient Temperature Average | Deg C | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Heat Transfer coefficient Circumference | | 2.38 | 1.62 | 1.49 | 1.37 | 1.32 | 1.24 | 1.17 | 6.92 |
| Heat Loss Circumference | Watts | 6.36 | 5.48 | 6.30 | 7.32 | 8.01 | 9.38 | 11.17 | 26.09 |
| Total Heat Loss/metre of pipe | Kcal/hr | 5.46 | 4.70 | 5.41 | 6.28 | 6.87 | 8.05 | 9.58 | 22.38 |
| Total Heat Loss/metre of pipe | Kcal/Day | 131.01 | 112.92 | 129.76 | 150.83 | 164.91 | 193.20 | 230.02 | 537.14 |
| Temperature drop in 1hr | Deg C | 27.15 | 12.84 | 9.30 | 6.21 | 5.01 | 3.65 | 2.58 | 71.24 |

# Table 16

| Calculation of Heat Loss From Pipes based on conductive loss with Rockwool insulation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| metal resistance ignored | | | | | | | | |
| Water Side Film coefficient | W/m sq/degc | 900 | | | | | | |
| Air side Film Coefficient | W/m sq/degc | 7 | | | | | | |
| Pipe Nominal Dia | mm | 15 | 20 | 25 | 32 | 40 | 50 | 65 |
| Thickness medium Class | mm | 2.65 | 2.65 | 3.25 | 3.25 | 3.25 | 3.65 | 3.65 |
| Inside Diameter | mm | 0.016 | 0.0216 | 0.0272 | 0.0359 | 0.0418 | 0.053 | 0.0688 |
| Volume | Litre/Meter | 0.20 | 0.37 | 0.58 | 1.01 | 1.37 | 2.21 | 3.72 |
| Diameter of Pipe Externnal | M | 0.0213 | 0.0269 | 0.0337 | 0.0424 | 0.0483 | 0.0603 | 0.0761 |
| Length | M | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Thickness | M | **0.025** | **0.025** | **0.025** | **0.05** | **0.05** | **0.05** | **0.05** |
| k | Watt/m/k | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| Dia ext of insulation | M | 0.0713 | 0.0769 | 0.0837 | 0.1424 | 0.1483 | 0.1603 | 0.1761 |
| Initial | | | | | | | | |
| Inside Temperature Average | Deg C | 55 | 55 | 55 | 55 | 55 | 55 | 55 |
| Ambient Temperature Average | Deg C | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Heat Transfer coefficient Circumfrence | | 2.73 | 2.47 | 2.26 | 1.46 | 1.38 | 1.26 | 1.16 |
| Heat Loss Circumfrence | Watts | 7.32 | 8.36 | 9.58 | 7.77 | 8.37 | 9.57 | 11.11 |
| Total Heat Loss/metre of pipe | Kcal/hr | 6.28 | 7.17 | 8.22 | 6.66 | 7.18 | 8.21 | 9.53 |
| Total Heat Loss/metre of pipe | Kcal/Day | 150.66 | 172.07 | 197.24 | 159.95 | 172.37 | 197.03 | 228.70 |
| Temperature drop in 1hr | Deg C | 31.22 | 19.57 | 14.14 | 6.58 | 5.23 | 3.72 | 2.56 |



# Table 17

| Calculation of Heat Loss From Pipes based on conductive loss with Nitroflex insulation 12 mm thick | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| metal resistance ignored | | | | | | | | |
| Water Side Film coefficient | W/m sq/degc | 900 | | | | | | |
| Air side Film Coefficient | W/m sq/degc | 7 | | | | | | |
| Pipe Nominal Dia | mm | 15 | 20 | 25 | 32 | 40 | 50 | 65 |
| Thickness medium Class | mm | 2.65 | 2.65 | 3.25 | 3.25 | 3.25 | 3.65 | 3.65 |
| Inside Diameter | mm | 0.016 | 0.0216 | 0.0272 | 0.0359 | 0.0418 | 0.053 | 0.0688 |
| Volume | Litre/Meter | 0.20 | 0.37 | 0.58 | 1.01 | 1.37 | 2.21 | 3.72 |
| Diameter of Pipe Externnal | M | 0.0213 | 0.0269 | 0.0337 | 0.0424 | 0.0483 | 0.0603 | 0.0761 |
| Length | M | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Thickness | M | **0.012** | **0.012** | **0.012** | **0.012** | **0.012** | **0.012** | **0.012** |
| k | Watt/m/k | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| Dia ext of insulation | M | 0.0453 | 0.0509 | 0.0577 | 0.0664 | 0.0723 | 0.0843 | 0.1001 |
| Initial | | | | | | | | |
| Inside Temperature Average | Deg C | 55 | 55 | 55 | 55 | 55 | 55 | 55 |
| Ambient Temperature Average | Deg C | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Heat Transfer coefficient Circumfrence | | 3.71 | 3.43 | 3.21 | 3.03 | 2.94 | 2.81 | 2.70 |
| Heat Loss Circumfrence | Watts | 9.93 | 11.60 | 13.60 | 16.13 | 17.84 | 21.29 | 25.80 |
| Total Heat Loss/metre of pipe | Kcal/hr | 8.52 | 9.96 | 11.67 | 13.84 | 15.30 | 18.26 | 22.14 |
| Total Heat Loss/metre of pipe | Kcal/Day | 204.47 | 238.94 | 280.09 | 332.21 | 367.31 | 438.31 | 531.37 |
| Temperature drop in 1hr | Deg C | 42.37 | 27.17 | 20.08 | 13.67 | 11.15 | 8.28 | 5.96 |

## Table 18

| Calculation of Heat Loss From CPVC Pipes Based on conductive loss without insulation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Film Resistance on inside and outside and pipe resistance considered | | | | | | | | |
| Water Side Film coefficient | W/m sq/degc | 900 | | | | | | |
| Air side Film Coefficient | W/m sq/degc | 7 | | | | | | |
| Pipe Nominal Dia | inch | 0.5 | 0.75 | 1 | 1.25 | 1.5 | 2 | 2.5 |
| Thickness Shedule 40 | inch | 0.109 | 0.113 | 0.133 | 0.14 | 0.145 | 0.154 | 0.203 |
| Inside Diameter | inch | 0.622 | 0.824 | 1.049 | 1.38 | 1.61 | 2.067 | 2.469 |
| Volume | Litre/Meter | 0.20 | 0.34 | 0.56 | 0.96 | 1.31 | 2.16 | 3.09 |
| Diameter of Pipe Exterrnal | inch | 0.84 | 1.05 | 1.315 | 1.66 | 1.9 | 2.375 | 2.875 |
| Length | M | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Thickness | M | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| k | Watt/m/k | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| Inside Temperature Average | Deg C | 55 | 55 | 55 | 55 | 55 | 55 | 55 |
| Ambient Temperature Average | Deg C | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Heat Transfer coefficient Circumfrence | W/m sq/degc | 9.209056 | 8.693258 | 8.530858 | 8.184346 | 8.026802 | 7.80967 | 7.861382 |
| Heat Loss Circumfrence | Watts | 18.28311 | 22.86411 | 28.56359 | 36.0502 | 41.24896 | 51.52497 | 61.95332 |
| Total Heat Loss/metre of pipe | Kcal/hr | 15.69 | 19.62 | 24.51 | 30.93 | 35.39 | 44.21 | 53.16 |
| Total Heat Loss/metre of pipe | Kcal/Day | 376.49 | 470.82 | 588.18 | 742.35 | 849.40 | 1061.00 | 1275.74 |
| Temperature drop in 1 hr stagnant water | Deg C | 80.02 | 57.02 | 43.95 | 32.05 | 26.95 | 20.42 | 17.21 |

## Table 19

| Calculation of Heat Loss From CPVC Pipes Based on conductive loss without insulation | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Film Resistance on inside and pipe resistance considered but wall as sink | | | | | | | | |
| Water Side Film coefficient | W/m sq/degc | 900 | | | | | | |
| Wall conductivity | Watt/m/k | 0.69 | | | | | | |
| Wall Thickness | m | 0.23 | | | | | | |
| Pipe Nominal Dia | inch | 0.5 | 0.75 | 1 | 1.25 | 1.5 | 2 | 2.5 |
| Thickness Shedule 40 | inch | 0.109 | 0.113 | 0.133 | 0.14 | 0.145 | 0.154 | 0.203 |
| Inside Diameter | inch | 0.62 | 0.82 | 1.05 | 1.38 | 1.61 | 2.07 | 2.47 |
| Volume | Litre/Meter | 0.196037 | 0.344043 | 0.557583 | 0.964976 | 1.31344 | 2.164907 | 3.088876 |
| Diameter of Pipe Exterrnal | inch | 0.84 | 1.05 | 1.315 | 1.66 | 1.9 | 2.375 | 2.875 |
| Length | M | **1** | **1** | **1** | **1** | **1** | **1** | **1** |
| Thickness | M | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| k | Watt/m/k | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| Inside Temperature Average | Deg C | 55 | 55 | 55 | 55 | 55 | 55 | 55 |
| Ambient Temperature Average | Deg C | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Heat Transfer coefficient Circumfrence | W/m sq/degc | 43.54886 | 35.00646 | 30.32145 | 25.47985 | 23.39772 | 20.82073 | 20.28602 |
| Heat Loss Circumfrence | Watts | 86.46 | 92.07 | 101.52 | 112.23 | 120.24 | 137.37 | 159.87 |
| Total Heat Loss/metre of pipe | Kcal/hr | 74.18 | 79.00 | 87.11 | 96.30 | 103.16 | 117.86 | 137.17 |
| Total Heat Loss/metre of pipe | Kcal/Day | 1780.37 | 1895.91 | 2090.59 | 2311.10 | 2475.95 | 2828.65 | 3292.01 |
| Temperature drop in 1 hr stagnant water | Deg C | 378.4077 | 229.612 | 156.2241 | 99.79098 | 78.54549 | 54.44136 | 44.40678 |





# Role of vents, pressure safety valves, make up cum expansion tanks in solar water heating systems

### Introduction

Solar water heating systems require some other components for the effective working and role of these components is important in the functioning of the solar water heating system.

### Objective

Objective of this chapter is to familiarize the designers and installers of solar water heating systems with the other components of the system which have important role to play in the functioning of the system. Proper selection and installation of these components is to be ensured for safety and functioning of the system.

### Other components

In a solar water heating system two things are happening simultaneously as the water is heated up.

1. The water is expanding as the temperature of water increases due to volumetric coefficient of expansion.
2. The solubility of dissolved air in water decreases with the rise in temperature of water and the dissolved air separates from water.

Under these conditions if provisions are not made for release or venting of the released air at higher temperatures, the pressure in the solar water heating system will rise. The provision for air release is made in the form of air release valves or vents. The provision for expansion of water is in the form of vents, expansion cum make up tanks and pressure relief valves. Pressure relief valve is an emergency provision and not meant for regular use.

The expansion cum make up tank is required in a closed loop system as it serves to meet contraction requirements of the system when the system becomes cool in the night.

The vents, air release valves are to be located at high points in the solar water heating system as air being lighter than water tends to move up in the system. Expansion cum make up tank, if it is vented type, needs to be located at higher level. However bellow type expansion cum make up tanks can be located at lower level in cooler part of the system.

Chapter 31

# Distribution piping details and how these affect energy consumption

**Introduction**

The distribution piping or hot water supply lines have a large role in providing the satisfactory performance of the solar water heating system. This piping is the one which delivers the water to the user and it has been responsible for major complaints from the users. Quite often the distribution piping is already in place before a solar water heating system is installed and the problems associated with the piping keep on creating dissatisfaction to the user. In case of improper distribution piping installed either by the customer or by the system provider, the solar water heating system being the new technology gets the bad name.

**Objective**

To look at the problems faced by users of solar water heating systems due to hot water distribution piping and suggest remedies

**Hot water distribution piping**

We shall discuss the problems associated with distribution piping as below.

1. The solar water heating system has a small capacity but is connected to a number of end user points. In such systems, the capacity of the system is not enough to meet the demand and there is continuous complaint from the user.
2. Even if the system is of adequate size, it may be perceived to be inadequate since it is connected to number of end user points with long pipes. Even with adequate insulation, it is not feasible to maintain temperature of water in the pipe for 24 hours under stagnant conditions. The ratio of volume to surface area of pipes is very small and there will be drop in temperature of water held in the pipe line, which needs to be replaced with hot water before the hot water reaches the tap.
3. The pipes are insulated in the exposed areas but are not insulated in the embedded portion of pipes in the walls and ceiling. In this situation the system will fail altogether if the lengths of such piping is not negligible. As the heat from the pipe will be continuously lost to the wall or ceiling and the water reaching the

   end-use point may be cold or lukewarm. Replacement of such pipes is the only solution available.



4. The diameter of supply pipes is very large and the volume of water stored in pipes is large. This water needs to be replaced every day before hot water supply is available at the end use point.
5. The distribution piping is being laid in such a manner that the pipe keeps going up and down before reaching the end use point. In such a situation, there will be very little flow of water as the line will remain air locked most of the time. It has become a common practice with number of sanitary consultants to prescribe piping with large diameter of pipes so that the air locking does not result in blockage and the air bubbles are  carried away trapped in flowing water at high speed. But use of this technique in case of hot water creates the additional problem of wastage of both heat and water.
6. A number of small capacity solar water heating systems are connected to a common inlet cold water supply header and to a common outlet hot water header. This is a very tricky situation as it very difficult to ensure that the flow of water from each of the systems will be equal as there may not be similarity in connections. Non uniform flows are likely to occur. This results in underutilization of some systems and overutilization of the other systems. In such cases there may be cold water reaching the end use point even when hot water is available in the storage tanks of some of the systems. Sometimes the situation is even worse when number of solar water heating systems of different capacity located at different levels are connected in this fashion.

Chapter 32

# Backup systems and controls

**Introduction**

Solar water heating systems will generally require a back up heating system to ensure availability of hot water at all times

**Objective**

To understand the requirement of back up heating systems and to look at various aspects of their functioning.

**Backup Systems and Controls**

The solar water heating systems have requirements of backup heating systems for the following reasons.

1. The requirement of hot water is present on days when generation of hot water is limited due to clouds.
2. There is a sudden requirement of extra hot water due to presence of guests or there are requirement which are not of regular nature.
3. The capacity planned is adequate for most of the period but may not be enough during extreme cold conditions when the demand is high and hot water generation is lower due to lower radiation levels.
4. The capacity planned is not enough for meeting the entire requirement due to limitation of area available for installation of solar collectors.

**In all such cases a conventional heating system is used as backup for the solar water heating system. The backup used are of generally two types–**

A temperature control system is must in both types of back up heating systems as mentioned above. This will ensure that the water is not heated beyond the required temperature. The backup heating capacity, of course, will be different in both the cases.

For larger systems where the backup heating devices are the hot water generator or boilers, the backup heating devices are of large capacity and may be used as booster type backup heating devices. These have built in controls and storages also.

1. In line Backup heating Systems : In this type of backup system, the hot water from the solar water heating system is taken out through the inline booster back up heating system to boost the temperature before supply of hot water to the end use point.

   The inline booster will have large heating capacity as it should meet the demand instantly. and the backup heating inbuilt within the storage tank may be smaller as it can carry out the heating over a long period.

   Inline boosters do not have additional controls as the system is kept ready all the time. And the backup system is brought into operation as and when the temperature of hot water going out of the solar water heating systems is at a temperature lower than the required value.

   This backup system is energy efficient but requires large installed capacity. In case of electrical systems it may require high connected load. If backup capacity is not sufficient, the flow of hot water may have to be maintained at very low levels.

2. Built in backup heating system: In this type of backup system, the heating of hot water is done within the storage tank and hence hot water may be drawn at any time at the required temperature for use.

   The built in backup heating system needs to have more controls. If these backup heating systems are kept in operation all the time the hot water tank may not have any cold water to be heated by solar energy or solar energy may only boost the temperature of water already heated by backup device. There are three ways of avoiding this situation.

1. By keeping the backup device in the upper one fourth to one third level of the storage tank and to set temperature of backup device at just the useful level. This setting may be lower than the normal solar water heating tank temperature. This way only a small part of the system is heated by back up and that too will happen only when the temperature of water in this small portion has fallen below the desired level.
2. The other way is to regulate the start of the backup heating by complex sensing system when the heat drawn is more and heating by solar is not available to meet this requirement. That is to sense the level of hot water in the tank, sense whether heating is likely before the demand arises (read the time of the day and associate it with the use pattern, sense the solar radiation and switch on the backup based on that).
3. To switch on the backup manually in the evening of a cloudy day for use on next day morning and switch off will be automatic as per temperature setting. Also it can be switched on days when requirement of hot water is more. The system can be brought back to normal solar heating when conditions return to normal.

# Estimation of energy consumption from back up under different configurations

**Introduction**

The energy consumption from the back up may be less or more depending on how the backup system works in tandem with the solar water heating system.

**Objective**

To explain how location and configuration of backup heating system affects the energy usage from the back up heating system.

**Back up heating system functioning**

As explained the description on backup heating systems and controls, the consumption of auxiliary heating is the least when the temperature hot water is boosted up inline of hot water supply. This happens because heating is done only when required. This however suffers from need of high capacity of back up heating to meet peak demand of water. This negates the advantage of solar water heating system in reducing peak load and connected load.

When the backup heating system which is built in the storage tank the advantage is taken of the storage capacity of the tank and heating can take place in the night hours when peak load problems are not there and also connected load can be small as there is a long time available for heating and a small heater may be sufficient for a fairly large system.

Such a system will however suffer from excessive power consumption if the backup is kept on all the time. The solar water heating also will be ineffective as the hot water tank will always be hot till the bottom.

The solution to this problem lies in either keeping the switching of the backup in manual mode and it is switched on only on cloudy days or on days of extra requirements. The thermostatic cut off is still required to avoid over heating of water and wastage of power.

If for reasons of convenience some people want to have the solar water heating system with back up always on the solar water heating system may have the inline backup system with high capacity or alternatively the backup may be located in upper 1/3 to ¼ of the tank and the thermostat must be adjusted to lowest acceptable level say 35 to 45 Deg centigrade range.



In such a system back up will come into operation only when the temperature in the upper 1/3 portion of the tank has fallen below the minimum acceptable and the bottom 2/3 of the tank will in cold condition. This way the excessive consumption of electricity can be avoided and at the same time advantage of reduced peak time and connected load can be balanced.

Chapter 34

# Consideration of safety in installation, use and maintenance

**Introduction**

It is important to ensure safety of personnel and equipment during installation of the solar water heating systems.

**Objective**

To discuss issues related to safety of personnel and equipment.

The safety aspects can be considered in two parts

1. Safety of solar water heating system and components during installation and use.
2. Safety of personnel working on installation, use and maintenance

For the safety of the solar water heating system in use has been considered in the design stage and suggestions have been made to incorporate these but may be enumerated again.

1. The supports for the solar collectors, storage tank, heat exchanger and piping have to be designed considering the self load and load of stored water, wind loads and earth quake loads.
2. The anchoring of the supports to the building structure and components to the supports must ensure the stability of the structure and the components of the solar water heating systems during stormy conditions and the earth quake
3. All electric connections must be made with proper tooling and should ensure no leakages under outdoor conditions. The equipment to which electrical connections are made must be earthed. All electric wires should run in whether proof conduits or must be weather proof protected cables. There should be no joints in the cables in a conduit. Connections must terminate in a cable box with terminal and no twisted cable type joints should be made.
4. The systems installed on roof top must have lightening arresters if the building does not have lightening arresters.
5. The equipment must be stored at a place protected from rain and storm. Supports for the equipment must be installed and anchored to building structure first and then only the equipment must be placed on the supports and restrained with the supports.
6. Wherever pipe lines are running at lower level and people may step over these, the damage to insulation is to be avoided by providing walk over structures.



Safety of personnel during installation, use and maintenance is very important for every installation of solar water heating system. This can be ensured by taking precaution at each stage and making provisions for safety.

1. There must be a proper access to the installation site for the personnel and equipment.
2. When working on roof terraces there must be boundaries, railing or other such protection for personnel. In the absence of such protection the personnel have to work with safety belts.
3. All equipment supports must have sharp edges removed in workshop before the supports are painted and finished for dispatch to site.
4. Provision must be made for handling of equipment, installation tools and tackles.
5. Access ways and platforms must be built for cleaning of solar collectors.
6. All personnel should wear shoes and helmets during installation.
7. All gauges and valves must be located in accessible areas.
8. Vents and overflow devices, safety valves must be positioned so that there is no chance of hot water falling on personnel during commissioning and maintenance and also during regular use.

# Commissioning of Solar Water Heating Systems and fault finding and correcting at commissioning stage

### Introduction

The solar water heating installation needs to be observed closely in the initial commissioning stage. Large number of problems faced by users at a later date can be eliminated by observing during the initial commissioning and rectification can be carried out.

### Objective

To emphasize the importance of observing the performance of the solar water heating system at the initial commissioning stage of the solar water heating system so that rectification if required may be carried out.

### Observation at commissioning stage

The entire system is to be checked for leakages first before carrying out the commissioning of the system and leakages, if any, are to be rectified, before starting the commissioning operation

1. The temperature rise in the system is to be observed. If there is a gradual rise in temperature and the solar water system stabilizes at the expected temperature the solar water heating system may have all its piping connections made properly.
2. The lack of rise in temperature at the tank indicates flow blockades which may be due to air locking or some obstruction in the pipe line or a closed valve or incase of closed loop systems the makeup tank not being filled.
3. Sudden rise in temperature is an indication of the flow being present but not at the desired velocity. It may be due to release of dissolved air in a closed loop system, which may cure itself in few minutes or it may be because of improper piping or pump.
4. Inadequate rise in temperature compared to design values indicates that the flow is too high.
5. The air release valves or vents need to be observed for escape of humid hot air.
6. Safety valves need to be checked.
7. The backup heating devices must be operated and checked for performance.
8. The control system must be checked for the desired performance parameters.
9. The distribution pipes need to be checked for proper flows and temperature at the outlet points.





# Fault finding and rectification in existing systems and rectification

### Introduction

If an existing installation is not performing up to design expectations, the solar water heating system need to be observed and rectification carried out. We have tried to provide information on design and installations of solar water heating systems. This information can also be used for looking at existing installations to improve the performance and life of the existing systems.

### Objective

To ensure that existing installation may be improved if these are performing to our satisfaction.

### Fault finding and Rectification in Existing Systems

Thermo-siphon solar water heating systems

1. The flow of hot water is very less while cold water supply is available at reasonable pressure – This could be caused by scale deposit in the outlet pipe and it needs to be cleaned or due to airlock in the pipe. If due to scaling it points towards another problem which may be noticed later. That the water is hard and collectors have started getting choked with scaling and need cleaning. In case this is happening in a system with heat exchanger, the heat exchanger surface needs cleaning.
2. The hot water temperature is low and the complete tank is not heated up- This also points towards blocking of fluid passages in the collector and the part of piping which heat transfer reduced due to scale formation and the flow is also restricted due to deposition of scale in fluid passages. The top cover of the glass feels very hot when touched during checking
3. The problem is same but the glass cover does not feel hot when touched. This may be caused by damage to collector coating which can be checked by visual examination.
4. Solar collectors are showing water droplets in the morning on the inside of the glass cover – This may be caused by leakages in the collector tubes or by leakage in the top cover seal.
5. The water gets heated up and is very hot in the evening but the temperature of water is low in the morning even when no water was used in the evening. – This could be caused by damage to the insulation of the tank or leakage in the tank with the leakage water seeping into the insulation making it wet.

6. Collector supports are rusted – Painting and cleaning of supports is needed.

7. Solar collectors are leaking – repair or replacement of collectors is required.

8. All collectors are in perfect order and in a system with heat exchanger no heating is taking place. – This could happen if there is no or insufficient heating fluid in the closed loop system.

9. Water is dripping from the tank – the tank requires repair or replacement of the tank and the insulation.

10. The makeup cum expansion tank is overflowing all the time – This may be due to leakage in the heat exchanger and the raw water from the tank entering the heat exchanger - The heat exchanger requires repair/ replacement

11. The solar system has come under shadow due to some construction in the neighborhood - The system needs to be shifted to a shadow free area.

12. The cladding over the tank and pipelines has developed holes – This happens in thin aluminum sheets getting damaged due to bird droppings. This needs replacement.

13. The MCB trips whenever back up is switched on – The electric heating element casing has got corroded and water has entered the insulation creating a short circuit.

Forced flow solar water heating systems- May have any of the above problems besides some other associated with pumps and controls.

1. Pump not operating during sunshine hours – This could happen because of

   No electric power

   Sensor malfunction

   Controller malfunction

   Pump failure

2. The pump is operating but switched on and off very frequently - This could be because of

   Small gap between on/off temperature setting

   Pump is of very high capacity and the flow being very high the temperature falls immediately when the pump starts running.

3. The pump is operating properly but is running continuously, still the output temperature is very high and the entire tank is not heated in a day – If collector and heat exchangers are in good condition , this could be because of



   Pump being smaller than required capacity or if there is air locking in the system

4. Primary circulation keeps operating in the night- This could be because of failure of control system.

5. The primary system is getting pressurized – this could be because of installation of a non-return valve in the line connecting the makeup cum expansion tank to the system. Because the expansion of water in the system does not get released in the expansion cum make up tank.

Chapter 37

# Designing systems with evacuated tube collectors

**Introduction**

Evacuated tube collectors have lower heat losses due the vacuum in the space between the absorber surface and the outer covering. The cost of ETC`s which have only glass used as material of construction are also cheaper. Due to this reason these systems are becoming popular.

**Objective**

To look at design techniques required for these systems where ever requirements different from solar flat plate collectors exist

**Designing Systems with Evacuated Tube Collectors**

The solar water heating with evacuated tube collectors are being built in the following configurations

1. Directly coupled solar water heating system

In these systems the collector tubes are directly attached to the storage tank and water in the storage tank fills up the interior of the tubes. Such systems have a composite support arrangement for the tubes and the tank. One end of the tube is inside the tank, sealed with a gasket. This gasket is generally made of high temperature silicone rubber material. The gasket material and the tube alignment with the opening play an important role in maintaining a leak proof joint. Such systems are made up to 200-250 litre per day capacity.

2. Solar water heating system with manifold for ETC Tubing

In these systems ETC manifold of up to 70 tubes are made. These manifolds have a square or rectangular cross section. These manifolds are sufficiently large to accommodate the tubing with gasket type connections. The manifold supports one end of the tube and the other end is supported on the structure. The tubes are mounted horizontally so that there could be thermo-siphon flow through the manifold. The tubes may be kept slightly inclined within the gasket limitations to have a better flow through the tubes. Large capacity system may be built this way with ETC. Sometimes these systems may be built with heat exchanger or with pumps. In these cases the arrangement of the pump and heat exchanger is in such a way that the tube to manifold connection is not subjected to pressure to avoid leakages from gaskets.



The manifold type of ETC system design is also used for indirect heating of water with a heat exchanger. Heat exchangers are similar in design to the heat exchanger used with flat plate collector systems.

# Table 20

| Calculation of Pressure Drop Through five collector | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| Collector Size | Height | | Width | | Projection | | | |
| | | 2.08 | | 1.07 | | 0.045 | | |
| Header | | Length | | Diameter | Thickness | ID | | |
| | | 1.16 | | 0.0254 | | 0.00071 | | 0.02398 |
| Riser | | Length | | Diameter | Thickness | ID | Number | |
| | | 1.9702 | | 0.0125 | | 0.0005 | 0.0115 | 9 |
| Riser Projection in Header | | | 0.002 | | No of collectors | | 5 | |
| Flow Rate | | | | | | | | |
| Litre/hr | Temp | viscosity | Av Velocity | Re | f | f loss | v loss | Total |
| per | Deg C | m sq/Sec | m/sec | | | mm | mm | mm of |
| collector | | | | | | water | water | water |
| 10 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.01538 | 319 | 0.2007 | 0.59 | 0.01205 | 0.597 |
| Header T | 60 | 0.00000048 | 0.01538 | 707 | 0.0905 | 0.26 | 0.01205 | 0.276 |
| Risers | 40 | 0.000000659 | 0.00297 | 52 | 1.2342 | 0.1 | 0.00045 | 0.096 |
| **Total** | | | | | | | | **0.969** |
| | | | | | | | | |
| 20 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.03075 | 638 | 0.1004 | 1.17 | 0.0482 | 1.218 |
| Header T | 60 | 0.00000048 | 0.03075 | 1414 | 0.0453 | 0.53 | 0.0482 | 0.576 |
| Risers | 40 | 0.000000659 | 0.00594 | 104 | 0.6171 | 0.19 | 0.0018 | 0.192 |
| **Total** | | | | | | | | **1.986** |
| | | | | | | | | |
| 30 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.04613 | 957 | 0.0669 | 1.76 | 0.10845 | 1.864 |
| Header T | 60 | 0.00000048 | 0.04613 | 2121 | 0.12 | 3.15 | 0.10845 | 3.256 |
| Risers | 40 | 0.000000659 | 0.00891 | 156 | 0.4114 | 0.29 | 0.00405 | 0.29 |
| **Total** | | | | | | | | **5.409** |
| | | | | | | | | |
| 40 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0615 | 1275 | 0.0502 | 2.34 | 0.1928 | 2.533 |
| Header T | 60 | 0.00000048 | 0.0615 | 2828 | 0.1 | 4.66 | 0.1928 | 4.856 |
| Risers | 40 | 0.000000659 | 0.01189 | 207 | 0.3086 | 0.38 | 0.0072 | 0.388 |
| **Total** | | | | | | | | **7.777** |
| | | | | | | | | |
| 50 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.07688 | 1594 | 0.0401 | 2.93 | 0.30126 | 3.226 |
| Header T | 60 | 0.00000048 | 0.07688 | 3535 | 0.09 | 6.56 | 0.30126 | 6.859 |
| Risers | 40 | 0.000000659 | 0.01486 | 259 | 0.2468 | 0.48 | 0.01125 | 0.487 |
| **Total** | | | | | | | | **10.573** |
| | | | | | | | | |
| 60 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.09226 | 1913 | 0.0335 | 3.51 | 0.43381 | 3.944 |
| Header T | 60 | 0.00000048 | 0.09226 | 4242 | 0.089 | 9.34 | 0.43381 | 9.772 |
| Risers | 40 | 0.000000659 | 0.01783 | 311 | 0.2057 | 0.57 | 0.0162 | 0.587 |
| **Total** | | | | | | | | **14.303** |
| | | | | | | | | |
| 70 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.10763 | 2232 | 0.12 | 17.14 | 0.59046 | 17.728 |
| Header T | 60 | 0.00000048 | 0.10763 | 4949 | 0.085 | 12.14 | 0.59046 | 12.73 |
| Risers | 40 | 0.000000659 | 0.0208 | 363 | 0.1763 | 0.67 | 0.02205 | 0.688 |
| **Total** | | | | | | | | **31.146** |
| | | | | | | | | |
| 80 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.12301 | 2551 | 0.11 | 20.52 | 0.77122 | 21.29 |
| Header T | 60 | 0.00000048 | 0.12301 | 5656 | 0.08 | 14.92 | 0.77122 | 15.694 |
| Risers | 40 | 0.000000659 | 0.02377 | 415 | 0.1543 | 0.76 | 0.0288 | 0.79 |
| **Total** | | | | | | | | **37.774** |



| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 90 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.13839 | 2870 | 0.1 | 23.61 | 0.97607 | 24.584 |
| Header T | 60 | 0.00000048 | 0.13839 | 6363 | 0.075 | 17.71 | 0.97607 | 18.682 |
| Risers | 40 | 0.000000659 | 0.02674 | 467 | 0.1371 | 0.86 | 0.03645 | 0.893 |
| **Total** | | | | | | | | **44.159** |
| | | | | | | | | |
| 100 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.15376 | 3188 | 0.1 | 29.15 | 1.20503 | 30.351 |
| Header T | 60 | 0.00000048 | 0.15376 | 7070 | 0.075 | 21.86 | 1.20503 | 23.064 |
| Risers | 40 | 0.000000659 | 0.02971 | 519 | 0.1234 | 0.95 | 0.045 | 0.997 |
| **Total** | | | | | | | | **54.412** |
| | | | | | | | | |
| 110 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.16914 | 3507 | 0.09 | 31.74 | 1.45809 | 33.198 |
| Header T | 60 | 0.00000048 | 0.16914 | 7778 | 0.073 | 25.74 | 1.45809 | 27.203 |
| Risers | 40 | 0.000000659 | 0.03269 | 570 | 0.1122 | 1.05 | 0.05445 | 1.101 |
| **Total** | | | | | | | | **61.502** |
| | | | | | | | | |
| 120 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.18451 | 3826 | 0.0167 | 7.02 | 1.73524 | 8.756 |
| Header T | 60 | 0.00000048 | 0.18451 | 8485 | 0.0075 | 3.17 | 1.73524 | 4.901 |
| Risers | 40 | 0.000000659 | 0.03566 | 622 | 0.1029 | 1.14 | 0.0648 | 1.207 |
| **Total** | | | | | | | | **14.864** |

# Table 21

| Calculation of Friction Pressure Drop in GI Pipes per meter length | | | | | | | |
|---|---|---|---|---|---|---|---|
| At 60 Degree Centigrade with Water | | | | | | | |
| Kinematic Viscosity of Water | 4.78E-07 | M sq /Sec | | | | | |
| | | | | | | | |
| Pipe Size NB | 15 | 20 | 25 | 32 | 40 | 50 | 65 |
| OD meter | 0.0213 | 0.0269 | 0.0337 | 0.0424 | 0.0483 | 0.0603 | 0.0761 |
| Thickness Medium Mtr | 0.00265 | 0.00265 | 0.00325 | 0.00325 | 0.00325 | 0.00365 | 0.00365 |
| ID meter | 0.016 | 0.0216 | 0.0272 | 0.0359 | 0.0418 | 0.053 | 0.0688 |
| Roughness | 0.009 | 0.007 | 0.006 | 0.004 | 0.004 | 0.003 | 0.002 |
| Flow Litre/Hour | 20 | 50 | 100 | 150 | 300 | 600 | 1200 |
| Velocity | 0.0276 | 0.0379 | 0.0478 | 0.0412 | 0.0607 | 0.0755 | 0.0897 |
| Reynold Number | 925 | 1713 | 2720 | 3092 | 5310 | 8376 | 12905 |
| Friction Factor | 0.069 | 0.037 | 0.053 | 0.048 | 0.041 | 0.038 | 0.033 |
| Pressure Drop mm water | 0.168 | 0.127 | 0.227 | 0.115 | 0.184 | 0.209 | 0.197 |
| | | | | | | | |
| Flow Litre/Hour | 30 | 75 | 150 | 225 | 450 | 900 | 1800 |
| Velocity | 0.0414 | 0.0569 | 0.0717 | 0.0617 | 0.0911 | 0.1133 | 0.1345 |
| Reynold Number | 1387 | 2569 | 4080 | 4637 | 7966 | 12565 | 19358 |
| Friction Factor | 0.046 | 0.053 | 0.047 | 0.044 | 0.04 | 0.034 | 0.031 |
| Pressure Drop mm water | 0.252 | 0.404 | 0.453 | 0.238 | 0.405 | 0.42 | 0.415 |
| | | | | | | | |
| Flow Litre/Hour | 40 | 100 | 200 | 300 | 600 | 1200 | 2400 |
| Velocity | 0.0553 | 0.0758 | 0.0956 | 0.0823 | 0.1215 | 0.1511 | 0.1793 |
| Reynold Number | 1850 | 3426 | 5441 | 6183 | 10621 | 16753 | 25811 |
| Friction Factor | 0.035 | 0.053 | 0.045 | 0.04 | 0.038 | 0.033 | 0.029 |
| Pressure Drop mm water | 0.337 | 0.719 | 0.771 | 0.385 | 0.683 | 0.724 | 0.691 |
| | | | | | | | |
| Flow Litre/Hour | 50 | 125 | 250 | 375 | 750 | 1500 | 3000 |
| Velocity | 0.0691 | 0.0948 | 0.1195 | 0.1029 | 0.1518 | 0.1889 | 0.2242 |
| Reynold Number | 2312 | 4282 | 6801 | 7729 | 13276 | 20941 | 32264 |
| Friction Factor | 0.057 | 0.048 | 0.044 | 0.039 | 0.036 | 0.032 | 0.028 |
| Pressure Drop mm water | 0.866 | 1.017 | 1.178 | 0.586 | 1.012 | 1.098 | 1.042 |
| | | | | | | | |
| Flow Litre/Hour | 60 | 150 | 300 | 450 | 900 | 1800 | 3600 |
| Velocity | 0.0829 | 0.1137 | 0.1434 | 0.1235 | 0.1822 | 0.2266 | 0.269 |
| Reynold Number | 2775 | 5138 | 8161 | 9275 | 15931 | 25129 | 38716 |
| Friction Factor | 0.053 | 0.045 | 0.042 | 0.038 | 0.035 | 0.031 | 0.028 |
| Pressure Drop mm water | 1.16 | 1.373 | 1.619 | 0.823 | 1.416 | 1.531 | 1.501 |
| | | | | | | | |
| Flow Litre/Hour | 70 | 175 | 350 | 525 | 1050 | 2100 | 4200 |
| Velocity | 0.0967 | 0.1327 | 0.1673 | 0.1441 | 0.2125 | 0.2644 | 0.3138 |
| Reynold Number | 3237 | 5995 | 9521 | 10820 | 18586 | 29317 | 45169 |
| Friction Factor | 0.052 | 0.044 | 0.041 | 0.036 | 0.034 | 0.03 | 0.027 |
| Pressure Drop mm water | 1.549 | 1.827 | 2.151 | 1.061 | 1.873 | 2.017 | 1.97 |
| | | | | | | | |
| Flow Litre/Hour | 80 | 200 | 400 | 600 | 1200 | 2400 | 4800 |
| Velocity | 0.1105 | 0.1516 | 0.1912 | 0.1647 | 0.2429 | 0.3022 | 0.3587 |
| Reynold Number | 3700 | 6851 | 10881 | 12366 | 21241 | 33505 | 51622 |
| Friction Factor | 0.052 | 0.044 | 0.039 | 0.036 | 0.034 | 0.029 | 0.027 |
| Pressure Drop mm water | 2.023 | 2.386 | 2.672 | 1.386 | 2.446 | 2.547 | 2.573 |



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Flow Litre/Hour | 90 | 225 | 450 | 675 | 1350 | 2700 | 5400 |
| Velocity | 0.1243 | 0.1706 | 0.2151 | 0.1852 | 0.2733 | 0.34 | 0.4035 |
| Reynold Number | 4162 | 7707 | 12241 | 13912 | 23897 | 37694 | 58074 |
| Friction Factor | 0.05 | 0.043 | 0.038 | 0.035 | 0.033 | 0.028 | 0.027 |
| Pressure Drop mm water | 2.462 | 2.952 | 3.295 | 1.705 | 3.005 | 3.112 | 3.256 |
| | | | | | | | |
| Flow Litre/Hour | 100 | 250 | 500 | 750 | 1500 | 3000 | 6000 |
| Velocity | 0.1382 | 0.1895 | 0.239 | 0.2058 | 0.3036 | 0.3777 | 0.4483 |
| Reynold Number | 4624 | 8564 | 13601 | 15458 | 26552 | 41882 | 64527 |
| Friction Factor | 0.048 | 0.042 | 0.038 | 0.035 | 0.033 | 0.027 | 0.027 |
| Pressure Drop mm water | 2.918 | 3.559 | 4.068 | 2.105 | 3.71 | 3.705 | 4.02 |
| | | | | | | | |
| Flow Litre/Hour | 150 | 375 | 750 | 1125 | 2250 | 4500 | 9000 |
| Velocity | 0.2072 | 0.2843 | 0.3585 | 0.3087 | 0.4554 | 0.5666 | 0.6725 |
| Reynold Number | 6937 | 12846 | 20402 | 23187 | 39828 | 62823 | 96791 |
| Friction Factor | 0.045 | 0.041 | 0.037 | 0.034 | 0.032 | 0.027 | 0.026 |
| Pressure Drop mm water | 6.156 | 7.818 | 8.912 | 4.601 | 8.094 | 8.335 | 8.71 |
| | | | | | | | |
| Flow Litre/Hour | 200 | 500 | 1000 | 1500 | 3000 | 6000 | 12000 |
| Velocity | 0.2763 | 0.379 | 0.478 | 0.4116 | 0.6073 | 0.7555 | 0.8966 |
| Reynold Number | 9249 | 17128 | 27203 | 30915 | 53104 | 83763 | 129054 |
| Friction Factor | 0.044 | 0.038 | 0.036 | 0.033 | 0.032 | 0.026 | 0.025 |
| Pressure Drop mm water | 10.701 | 12.882 | 15.416 | 7.938 | 14.389 | 14.27 | 14.889 |

# Table 22

| Calculation of Friction Pressure Drop in GI Pipes per meter length | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| At 20 Degree Centigrade with Water | | | | | | | |
| Kinematic Viscosity of Water | 1.06E-06 | M sq /Sec | | | | | |
| | | | | | | | |
| Pipe Size NB | 15 | 20 | 25 | 32 | 40 | 50 | 65 |
| OD meter | 0.0213 | 0.0269 | 0.0337 | 0.0424 | 0.0483 | 0.0603 | 0.0761 |
| Thickness Medium Mtr | 0.00265 | 0.00265 | 0.00325 | 0.00325 | 0.00325 | 0.00365 | 0.00365 |
| ID meter | 0.016 | 0.0216 | 0.0272 | 0.0359 | 0.0418 | 0.053 | 0.0688 |
| Roughness | 0.009 | 0.007 | 0.006 | 0.004 | 0.004 | 0.003 | 0.002 |
| Flow Litre/Hour | 20 | 50 | 100 | 150 | 300 | 600 | 1200 |
| Velocity | 0.0276 | 0.0379 | 0.0478 | 0.0412 | 0.0607 | 0.0755 | 0.0897 |
| Reynold Number | 417 | 772 | 1227 | 1394 | 2395 | 3777 | 5820 |
| Friction Factor | 0.153 | 0.083 | 0.052 | 0.046 | 0.027 | 0.043 | 0.036 |
| Pressure Drop mm water | 0.373 | 0.281 | 0.223 | 0.11 | 0.12 | 0.236 | 0.214 |
| | | | | | | | |
| Flow Litre/Hour | 30 | 75 | 150 | 225 | 450 | 900 | 1800 |
| Velocity | 0.0414 | 0.0569 | 0.0717 | 0.0617 | 0.0911 | 0.1133 | 0.1345 |
| Reynold Number | 626 | 1159 | 1840 | 2091 | 3592 | 5666 | 8729 |
| Friction Factor | 0.102 | 0.055 | 0.035 | 0.031 | 0.043 | 0.037 | 0.034 |
| Pressure Drop mm water | 0.56 | 0.421 | 0.335 | 0.166 | 0.435 | 0.457 | 0.456 |
| | | | | | | | |
| Flow Litre/Hour | 40 | 100 | 200 | 300 | 600 | 1200 | 2400 |
| Velocity | 0.0553 | 0.0758 | 0.0956 | 0.0823 | 0.1215 | 0.1511 | 0.1793 |
| Reynold Number | 834 | 1545 | 2453 | 2788 | 4789 | 7555 | 11639 |
| Friction Factor | 0.077 | 0.041 | 0.048 | 0.047 | 0.04 | 0.036 | 0.032 |
| Pressure Drop mm water | 0.746 | 0.562 | 0.822 | 0.452 | 0.719 | 0.79 | 0.762 |
| | | | | | | | |
| Flow Litre/Hour | 50 | 125 | 250 | 375 | 750 | 1500 | 3000 |
| Velocity | 0.0691 | 0.0948 | 0.1195 | 0.1029 | 0.1518 | 0.1889 | 0.2242 |
| Reynold Number | 1043 | 1931 | 3067 | 3485 | 5987 | 9443 | 14549 |
| Friction Factor | 0.061 | 0.033 | 0.047 | 0.045 | 0.039 | 0.035 | 0.032 |
| Pressure Drop mm water | 0.933 | 0.702 | 1.258 | 0.677 | 1.096 | 1.201 | 1.191 |
| | | | | | | | |
| Flow Litre/Hour | 60 | 150 | 300 | 450 | 900 | 1800 | 3600 |
| Velocity | 0.0829 | 0.1137 | 0.1434 | 0.1235 | 0.1822 | 0.2266 | 0.269 |
| Reynold Number | 1251 | 2317 | 3680 | 4182 | 7184 | 11332 | 17459 |
| Friction Factor | 0.051 | 0.028 | 0.046 | 0.045 | 0.039 | 0.035 | 0.031 |
| Pressure Drop mm water | 1.12 | 0.843 | 1.773 | 0.974 | 1.578 | 1.729 | 1.662 |
| | | | | | | | |
| Flow Litre/Hour | 70 | 175 | 350 | 525 | 1050 | 2100 | 4200 |
| Velocity | 0.0967 | 0.1327 | 0.1673 | 0.1441 | 0.2125 | 0.2644 | 0.3138 |
| Reynold Number | 1460 | 2703 | 4293 | 4879 | 8381 | 13220 | 20369 |
| Friction Factor | 0.044 | 0.055 | 0.046 | 0.045 | 0.037 | 0.034 | 0.03 |
| Pressure Drop mm water | 1.306 | 2.284 | 2.413 | 1.326 | 2.038 | 2.286 | 2.189 |
| | | | | | | | |
| Flow Litre/Hour | 80 | 200 | 400 | 600 | 1200 | 2400 | 4800 |
| Velocity | 0.1105 | 0.1516 | 0.1912 | 0.1647 | 0.2429 | 0.3022 | 0.3587 |
| Reynold Number | 1668 | 3089 | 4907 | 5576 | 9579 | 15109 | 23278 |
| Friction Factor | 0.038 | 0.052 | 0.046 | 0.043 | 0.036 | 0.033 | 0.029 |
| Pressure Drop mm water | 1.493 | 2.82 | 3.152 | 1.655 | 2.59 | 2.898 | 2.763 |



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Flow Litre/Hour | 90 | 225 | 450 | 675 | 1350 | 2700 | 5400 |
| Velocity | 0.1243 | 0.1706 | 0.2151 | 0.1852 | 0.2733 | 0.34 | 0.4035 |
| Reynold Number | 1877 | 3476 | 5520 | 6274 | 10776 | 16998 | 26188 |
| Friction Factor | 0.034 | 0.048 | 0.044 | 0.4 | 0.035 | 0.033 | 0.029 |
| Pressure Drop mm water | 1.679 | 3.295 | 3.815 | 19.485 | 3.187 | 3.668 | 3.497 |
| | | | | | | | |
| Flow Litre/Hour | 100 | 250 | 500 | 750 | 1500 | 3000 | 6000 |
| Velocity | 0.1382 | 0.1895 | 0.239 | 0.2058 | 0.3036 | 0.3777 | 0.4483 |
| Reynold Number | 2085 | 3862 | 6133 | 6971 | 11973 | 18886 | 29098 |
| Friction Factor | 0.058 | 0.048 | 0.044 | 0.038 | 0.035 | 0.032 | 0.028 |
| Pressure Drop mm water | 3.526 | 4.068 | 4.71 | 2.285 | 3.934 | 4.391 | 4.169 |
| | | | | | | | |
| Flow Litre/Hour | 150 | 375 | 750 | 1125 | 2250 | 4500 | 9000 |
| Velocity | 0.2072 | 0.2843 | 0.3585 | 0.3087 | 0.4554 | 0.5666 | 0.6725 |
| Reynold Number | 3128 | 5793 | 9200 | 10456 | 17960 | 28329 | 43647 |
| Friction Factor | 0.054 | 0.045 | 0.041 | 0.036 | 0.034 | 0.03 | 0.028 |
| Pressure Drop mm water | 7.387 | 8.581 | 9.876 | 4.871 | 8.6 | 9.261 | 9.38 |
| | | | | | | | |
| Flow Litre/Hour | 200 | 500 | 1000 | 1500 | 3000 | 6000 | 12000 |
| Velocity | 0.2763 | 0.379 | 0.478 | 0.4116 | 0.6073 | 0.7555 | 0.8966 |
| Reynold Number | 4171 | 7724 | 12267 | 13941 | 23947 | 37773 | 58196 |
| Friction Factor | 0.049 | 0.044 | 0.038 | 0.031 | 0.03 | 0.028 | 0.027 |
| Pressure Drop mm water | 11.917 | 14.916 | 16.272 | 7.457 | 13.49 | 15.367 | 16.08 |

# Table 23

| Calculation of Pressure Drop Through Single Collector | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| Collector Size Height | | | Width | | Projection | | | |
| | | 2.08 | | 1.07 | | 0.045 | | |
| Header | | Length | | Diameter | | Thickness | ID | |
| | | 1.16 | | 0.0254 | | 0.00071 | | 0.02398 |
| Riser | | Length | | Diameter | | Thickness | ID | Number |
| | | 1.9702 | | 0.0125 | | 0.0005 | 0.0115 | 9 |
| Riser Projection in Header | | | 0.002 | | | | | |
| Flow Rate | | | | | | | | |
| Litre/hr | Temp | viscosity | Velocity | Re | f | f loss | v loss | Total |
| | Deg C | m sq/Sec | m/sec | | | mm water | mm water | |
| 10 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0037 | 76 | 0.843 | 0.028 | 0.001 | 0.029 |
| Header T | 60 | 0.00000048 | 0.0037 | 168 | 0.38 | 0.013 | 0.001 | 0.013 |
| Risers | 40 | 0.00000066 | 0.003 | 52 | 1.234 | 0.095 | 0 | 0.096 |
| Total | | | | | | | | 0.137 |
| | | | | | | | | |
| 20 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0073 | 152 | 0.422 | 0.056 | 0.003 | 0.058 |
| Header T | 60 | 0.00000048 | 0.0073 | 337 | 0.19 | 0.025 | 0.003 | 0.028 |
| Risers | 40 | 0.00000066 | 0.0059 | 104 | 0.617 | 0.19 | 0.002 | 0.192 |
| Total | | | | | | | | 0.278 |
| | | | | | | | | |
| 30 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.011 | 228 | 0.281 | 0.084 | 0.006 | 0.09 |
| Header T | 60 | 0.00000048 | 0.011 | 505 | 0.127 | 0.038 | 0.006 | 0.044 |
| Risers | 40 | 0.00000066 | 0.0089 | 156 | 0.411 | 0.285 | 0.004 | 0.29 |
| Total | | | | | | | | 0.423 |
| | | | | | | | | |
| 40 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0146 | 304 | 0.211 | 0.111 | 0.011 | 0.122 |
| Header T | 60 | 0.00000048 | 0.0146 | 673 | 0.095 | 0.05 | 0.011 | 0.061 |
| Risers | 40 | 0.00000066 | 0.0119 | 207 | 0.309 | 0.381 | 0.007 | 0.388 |
| Total | | | | | | | | 0.571 |
| | | | | | | | | |
| 50 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0183 | 380 | 0.169 | 0.139 | 0.017 | 0.156 |
| Header T | 60 | 0.00000048 | 0.0183 | 842 | 0.076 | 0.063 | 0.017 | 0.08 |
| Risers | 40 | 0.00000066 | 0.0149 | 259 | 0.247 | 0.476 | 0.011 | 0.487 |
| Total | | | | | | | | 0.723 |
| | | | | | | | | |
| 60 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0439 | 911 | 0.07 | 0.334 | 0.098 | 0.433 |
| Header T | 60 | 0.00000048 | 0.0439 | 2020 | 0.032 | 0.151 | 0.098 | 0.249 |
| Risers | 40 | 0.00000066 | 0.0178 | 311 | 0.206 | 0.571 | 0.016 | 0.587 |
| Total | | | | | | | | 1.269 |
| | | | | | | | | |
| 70 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0256 | 531 | 0.12 | 0.195 | 0.033 | 0.228 |
| Header T | 60 | 0.00000048 | 0.0256 | 1178 | 0.054 | 0.088 | 0.033 | 0.121 |
| Risers | 40 | 0.00000066 | 0.0208 | 363 | 0.176 | 0.666 | 0.022 | 0.688 |
| Total | | | | | | | | 1.038 |
| | | | | | | | | |
| 80 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0293 | 607 | 0.105 | 0.223 | 0.044 | 0.267 |
| Header T | 60 | 0.00000048 | 0.0293 | 1347 | 0.048 | 0.1 | 0.044 | 0.144 |
| Risers | 40 | 0.00000066 | 0.0238 | 415 | 0.154 | 0.761 | 0.029 | 0.79 |
| Total | | | | | | | | 1.201 |



| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 90 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0329 | 683 | 0.094 | 0.251 | 0.055 | 0.306 |
| Header T | 60 | 0.00000048 | 0.0329 | 1515 | 0.042 | 0.113 | 0.055 | 0.168 |
| Risers | 40 | 0.00000066 | 0.0267 | 467 | 0.137 | 0.856 | 0.036 | 0.893 |
| Total | | | | | | | | 1.367 |
| | | | | | | | | |
| 100 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0366 | 759 | 0.084 | 0.279 | 0.068 | 0.347 |
| Header T | 60 | 0.00000048 | 0.0366 | 1683 | 0.038 | 0.126 | 0.068 | 0.194 |
| Risers | 40 | 0.00000066 | 0.0297 | 519 | 0.123 | 0.952 | 0.045 | 0.997 |
| Total | | | | | | | | 1.537 |
| | | | | | | | | |
| 110 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0403 | 835 | 0.077 | 0.306 | 0.083 | 0.389 |
| Header T | 60 | 0.00000048 | 0.0403 | 1851 | 0.035 | 0.138 | 0.083 | 0.221 |
| Risers | 40 | 0.00000066 | 0.0327 | 570 | 0.112 | 1.047 | 0.054 | 1.101 |
| Total | | | | | | | | 1.711 |
| | | | | | | | | |
| 120 | | | | | | | | |
| Header B | 20 | 0.00000106 | 0.0439 | 911 | 0.07 | 0.334 | 0.098 | 0.433 |
| Header T | 60 | 0.00000048 | 0.0439 | 2020 | 0.032 | 0.151 | 0.098 | 0.249 |
| Risers | 40 | 0.00000066 | 0.0357 | 622 | 0.103 | 1.142 | 0.065 | 1.207 |
| Total | | | | | | | | 1.888 |

# Table 24

| Thermosiphonic Head Calculations Initial Heating | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Collector Size Height | | Width | | | Projection | | | | |
| | | 2080 | | 1070 | | 45 | | | |
| Header | | Length | | Diameter | | Thickness | | | |
| ID | | | | | | | | | |
| | | 1160 | | 25.4 | | 0.71 | | | |
| 23.98 | | | | | | | | | |
| Riser | | Length | | Diameter | | Thickness | | | |
| Number | | | | | | | | | |
| | | 1970.2 | | 12.5 | | 0.5 | | | |
| 9 | | | | | | | | | |
| Riser Projection in Header | | 2 | | | | | | | |
| Riser Header to Header | Angle Collector | Height Riser * | Height Header Tank inlet | Height Tank inlet to outlet | Temp collector top | Water Density at Temp | Temp Tank Bottom | Water Density at Temp | Differential Head water col |
| Mtr | Deg | Mtr | Mtr | Mtr | Deg C | Kg/Cub M | | | mm |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 60 | 983.2 | 20 | 998.2 | 17.62 |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 50 | 988.1 | 20 | 998.2 | 11.86 |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 45 | 990.6 | 20 | 998.2 | 8.93 |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 40 | 992.1 | 20 | 998.2 | 7.16 |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 35 | 994 | 20 | 998.2 | 4.93 |
| 1.9662 | 43 | 1.341 | 0.15 | 0.33 | 30 | 995.7 | 20 | 998.2 | 2.94 |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 60 | 983.2 | 20 | 998.2 | 16.02 |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 50 | 988.1 | 20 | 998.2 | 10.79 |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 45 | 990.6 | 20 | 998.2 | 8.12 |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 40 | 992.1 | 20 | 998.2 | 6.51 |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 35 | 994 | 20 | 998.2 | 4.49 |
| 1.9662 | 35 | 1.128 | 0.15 | 0.33 | 30 | 995.7 | 20 | 998.2 | 2.67 |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 60 | 983.2 | 20 | 998.2 | 13.79 |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 50 | 988.1 | 20 | 998.2 | 9.29 |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 45 | 990.6 | 20 | 998.2 | 6.99 |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 40 | 992.1 | 20 | 998.2 | 5.61 |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 35 | 994 | 20 | 998.2 | 3.86 |
| 1.9662 | 25 | 0.831 | 0.15 | 0.33 | 30 | 995.7 | 20 | 998.2 | 2.3 |



# Table 25

| System Size 500 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Tube Dia | 0.0254 | | | | | |
| | | | | Thickness | 0.0016 | | | | | |
| | | | | Tank side Water | | | | Collector side water | | |
| T tank inlet | 20 | °C | | hc | | | | hh | | |
| T tank top | 60 | °C | | water properties at avg temp | | | | water properties at avg temp | | |
| T collect oulet | 70 | °C | | **40** | | | | **50** | | |
| T collect inlet | 30 | | °C | | ρ | 992.3 | | | ρ | 986 |
| Flow collector | 100 | | LPH | | μ | 6.50E-04 | | | μ | 5.04E-04 |
| | | | | √ | 6.59E-07 | m²/sec | | √ | 5.56E-07 | |
| Q | 4000 | Kcal | | Pr | 4.31 | | | Pr | 3.54 | |
| | 4648 | W | | K | 0.634 | | | K | 0.648 | |
| | | | | b | 0.000387 | Unit | | b | 0.000449 | |
| For Counter flow | | | | | | Meter | | Dh | 0.0222 | mm |
| □1 | 10 | | | Gr | 7.16E+05 | m/sec | | Vm | 0.07 | m/sec |
| □2 | 10 | | | Nuo | 0.36 | | | Re | 2.86E+03 | |
| □m | 10 | | | Nu | 24.18 | | | Nu | 2.22E+01 | |
| | | | | ho | 603.53 | | | hh | 649.01 | |
| | | | | f | 0.0005 | | | | | |
| | | | | h | 255.11 | | | | | |
| | | | | A | 1.82 | m² | | | | |
| | | | | 22.83 | Meter | | | | | |
| | **Coil pressure drop** | | | | | | | | | |
| | Tube Flow | Re | | 8680 | | | | | | |
| | | f | | 0.032 | | | | | | |
| | | Length | | 22.83 | | | | | | |
| | | V | | 0.07 | | | | | | |
| | Pressure Drop | | ΔP | 8.6365 | mm water | | | | | |
| | Velocity head | | | 0.262 | mm water | | | | | |

# Table 26

| Calculation of Solar radiation at Incline plane and collector output at Delhi | | | |
|---|---|---|---|
| Month | Jan | | |
| n | 15 | number of the day from the beginning of the year | |
| δ | -21.3 | | -9.3 |
| δ rad | -0.37 | | -0.16 |
| Ydeg | 0 | | 0 |
| Y rad | 0 | | 0 |
| Φ deg | 28.6 | | 28.58 |
| Φ rad | 0.5 | | 0.5 |
| ß deg | 43 | | 43 |
| ß rad | 0.75 | | 0.75 |
| bo | 0.1 | | |
| Cold input | 15 | | |
| To | 60 | | |
| Ti | 37.5 | | |
| A | 2 | | |
| Fr τα | 0.65 | | |
| Fr Ul | 4 | Watt/sq meter | |

| LAT ending | G global | Gm Direct | Gm diffuse | ω deg | ω rad | Cos□ | Cos□z | Rb | Rd | Rbe | I | Ta | Qu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 0 | 0 | 0 | -97.5 | -1.702 | -0.03 | -0.28 | 0 | 0 | 0 | 0 | 8.9 | |
| 7 | 4 | 1 | 3 | -82.5 | -1.44 | 0.21 | -0.07 | -3 | 3 | -2 | 1 | 8.6 | |
| 8 | 96 | 45 | 51 | -67.5 | -1.178 | 0.44 | 0.14 | 140 | 44 | 122 | 166 | 8.7 | |
| 9 | 271 | 168 | 103 | -52.5 | -0.916 | 0.64 | 0.32 | 331 | 89 | 312 | 402 | 11 | 310 |
| 10 | 433 | 293 | 140 | -37.5 | -0.655 | 0.81 | 0.48 | 497 | 121 | 485 | 606 | 13.8 | 598 |
| 11 | 556 | 396 | 160 | -22.5 | -0.393 | 0.92 | 0.58 | 628 | 139 | 623 | 762 | 16.3 | 821 |
| 12 | 618 | 444 | 174 | -7.5 | -0.131 | 0.99 | 0.64 | 686 | 151 | 685 | 835 | 17 | 922 |
| 13 | 615 | 443 | 172 | 7.5 | 0.131 | 0.99 | 0.64 | 684 | 149 | 683 | 832 | 17.8 | 924 |
| 14 | 552 | 390 | 162 | 22.5 | 0.393 | 0.92 | 0.58 | 619 | 140 | 614 | 754 | 19.6 | 837 |
| 15 | 430 | 293 | 137 | 37.5 | 0.655 | 0.81 | 0.48 | 497 | 119 | 485 | 603 | 19.7 | 642 |
| 16 | 268 | 168 | 100 | 52.5 | 0.916 | 0.64 | 0.32 | 331 | 87 | 312 | 399 | 19.6 | 376 |
| 17 | 99 | 48 | 51 | 67.5 | 1.178 | 0.44 | 0.14 | 150 | 44 | 130 | 175 | 19.1 | 80 |
| 18 | 5 | 2 | 3 | 82.5 | 1.44 | 0.21 | -0.07 | -6 | 3 | -4 | 0 | 17.2 | |
| 19 | 0 | 0 | 0 | 97.5 | 1.702 | -0.03 | -0.28 | 0 | 0 | 0 | 0 | 15.5 | |
| **Total** | **3947** | **2691** | **1256** | | | | | **4553** | **1087** | | | | **5509** |



# Table 27

| Calculation of Solar radiation at Incline plane and collector output at Delhi | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | Jan | n | | | | | | | | | | | |
| | δ | -21.3 | 15 | | Ydeg | 0 | | Φ | 28.58 | ß deg | 43 | bo | 0.1 |
| | δ rad | -0.37 | | | Y rad | 0 | | Φ rad | 0.5 | ß rad | 0.75 | Fr τα | 0.65 |
| | Cold input | 15 | | To | 60 | | Ti | 37.5 | | | | | |
| | A | 2 | | | | | | | | | | | |
| | Fr Uι | 4Watt/sq metre | | | | | | | | | | | |

| LAT ending | G global | Gm Direct | Gm diffuse | ω deg | ω rad | Cos□ | Cos□z | Rb | Rd | Rbe | I | Ta | Qu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 0 | 0 | 0 | -97.5 | -1.702 | -0.03 | -0.28 | 0 | 0 | 0 | 0 | 8.9 | |
| 7 | 4 | 1 | 3 | -82.5 | -1.44 | 0.21 | -0.07 | -3 | 3 | -2 | 1 | 8.6 | |
| 8 | 96 | 45 | 51 | -67.5 | -1.178 | 0.44 | 0.14 | 140 | 44 | 122 | 166 | 8.7 | |
| 9 | 271 | 168 | 103 | -52.5 | -0.916 | 0.64 | 0.32 | 331 | 89 | 312 | 402 | 11 | 310 |
| 10 | 433 | 293 | 140 | -37.5 | -0.655 | 0.81 | 0.48 | 497 | 121 | 485 | 606 | 13.8 | 598 |
| 11 | 556 | 396 | 160 | -22.5 | -0.393 | 0.92 | 0.58 | 628 | 139 | 623 | 762 | 16.3 | 821 |
| 12 | 618 | 444 | 174 | -7.5 | -0.131 | 0.99 | 0.64 | 686 | 151 | 685 | 835 | 17 | 922 |
| 13 | 615 | 443 | 172 | 7.5 | 0.131 | 0.99 | 0.64 | 684 | 149 | 683 | 832 | 17.8 | 924 |
| 14 | 552 | 390 | 162 | 22.5 | 0.393 | 0.92 | 0.58 | 619 | 140 | 614 | 754 | 19.6 | 837 |
| 15 | 430 | 293 | 137 | 37.5 | 0.655 | 0.81 | 0.48 | 497 | 119 | 485 | 603 | 19.7 | 642 |
| 16 | 268 | 168 | 100 | 52.5 | 0.916 | 0.64 | 0.32 | 331 | 87 | 312 | 399 | 19.6 | 376 |
| 17 | 99 | 48 | 51 | 67.5 | 1.178 | 0.44 | 0.14 | 150 | 44 | 130 | 175 | 19.1 | 80 |
| 18 | 5 | 2 | 3 | 82.5 | 1.44 | 0.21 | -0.07 | -6 | 3 | -4 | 0 | 17.2 | |
| 19 | 0 | 0 | 0 | 97.5 | 1.702 | -0.03 | -0.28 | 0 | 0 | 0 | 0 | 15.5 | |
| **Total** | **3947** | **2691** | **1256** | | | | | **4553** | **1087** | | | | **5509** |

# Table 28

| Calculation Of Tube in Tube Heat Excahnger | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size of system | | 10000 | Litre Per day | Temperature | 60 | Deg C | | | T mean | | | | |
| Primary Flow rate | | 2285.71 | Litre per hour | Temperature | 65 | Deg C | | 30 | Deg C | 47.5 | | | |
| Secondary Flow rate | | 2000 | Litre per hour | Temperature | 60 | Deg C | | 20 | Deg C | 40 | | | |
| | | | | | | | | | | | | | |
| Flow conditions | Counter Flow | | Primary in annulus and Secondary in inner Tube | | | | | | | | | | |
| Length Of Individual tubes | | | | | | | | 2.7 | Meter | | | | |
| Material | SS 304 L | Tubes | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | OD | Thickness | ID | Area | | Velocity | Equivalent | K Viscosity | Conductivity | Reynold | Prandtl | Nusset | Heat trans |
| | Meter | Meter | Meter | Sq Meter | | M/Sec | dia Meter | SqM/ Sec | W/m-K | No | Pr | Nu | Coefficient |
| | | | | | | | | | | | | | h |
| Outer Tube | 0.0381 | 0.0012 | 0.0357 | 0.001 | | | | | | | | | W/sqm -K |
| Inner Tube | 0.0254 | 0.0012 | 0.023 | 0.0004 | | 1.337 | | 6.59E-07 | 0.634 | 46668 | 4.31 | 224.3 | 3982.52 |
| Annulus | | | | 0.0005 | | 1.285 | 0.0248 | 5.82E-07 | 0.645 | 54685 | 3.73 | 265 | 6898.05 |
| | | | | | | | | | | | | | |
| Fouling factor | | | 0.0005 | | | | | | | | | | |
| Ignoring Metal Resistance as negligible | | | | | | | | | | | | | |
| Over all heat transfer coefficient | | | 1084.3 | W/sqm -K | | | | | | | | | |
| | | | | | | | | | | | | | |
| Q | | 80000 | Kcal/Hr | | | | | | | | | | |
| | | 93240 | W | | | | | | | | | | |
| LMTD | | 7.21 | deg C | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Area Required | | 11.92 | Sq Meter | | | | | | | | | | |
| | | | | | | | | | | | | | |
| No of tubes | | 55.33 | 56 | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Pressure Drop Through heat Exchanger | | | | | | | | | | | | | |
| Primary Side | Length | 151.2 | meter | | | Secondary Side | | length | 168 | meter | | | |
| Dia | | 0.0103 | meter | | | | | Dia | 0.023 | meter | | | |
| Re | | 22733 | | | | | | | 46668 | | | | |
| | | | | | | | | | | | | | |
| f | | 0.028 | | | | | | f | 0.024 | | | | |
| | | | | | | | | | | | | | |
| Friction Pressure Loss | | 34.57 | Meter water column | | | | | 15.98 | Meter water column | | | | |
| | | | | | | | | | | | | | |
| Velocity Head | | 0.08 | Meter water column | | | | | 0.09113 | Meter water column | | | | |
| | | | | | | | | | | | | | |
| Loss due to velocity | | | | | | | | | | | | | |
| head loss | | 4.71 | Meter water column | | | | | 5.1 | Meter water column | | | | |
| | | | | | | | | | | | | | |
| **Total** | | **39.28** | **Meter water column** | | | | | **21.08** | **Meter water column** | | | | |



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