SOLAR Heating for Industrial Process

Together Toward Efficient Production

Best Practice Manual in Manufacturing the Main Components of Solar Water Thermal Systems

2020

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List of Acronyms

CE	Chemonics Egypt
ETC	Evacuated Tube Collector
FPC	Flat Plate Collector
GEF	Global Environment Facility
GMAW	Gas Metal Arc Welding).
GSWH	Global Solar Water Heating
IRENA	International Renewable Energy Agency
MIG	Metal Inert Gas
MAG	Metal Active Gas
RTU	Ready To Use
SME	Small and Medium Enterprises
SPF	Institute Fur Solar technik
SWH	Solar Water Heating
TIG	Tungsten Inert Gas Welding
ToR	Terms of Reference
UNIDO	United Nations Industrial Development Organization
W.r.t	With Respect To

Acknowledgment

Utilizing Solar Energy for Industrial Process Heat in Egyptian Industry (SHIP) project herby express special thanks and gratitude for the consortium of Chemonics Egypt Consultants and Swiss Solar Technology Institute (SPF) for developing this best practice manual and effectively transferring this knowledge to our team. This report would not have been possible to undertake without their valuable support and dedication.

This manual was developed under the supervision of the United Nations Industrial Development Organization (UNIDO) within the scope of Utilizing Solar Energy for Industrial Process Heat in Egyptian Industry (SHIP)project. The project is funded by the Global Environmental Facility (GEF) and implemented by UNIDO in cooperation with the Ministry of Trade and Industry of Egypt (MTI).

Executive summary

Solar Water Heating in Industrial Process (SHIP) project supported by The United Nation Industrial Development Organization (UNIDO) developed a national roadmap in September 2019 aiming at strengthening the quality of locally manufactured products and components related to solar water heaters and solar thermal technologies in Egypt. The SHIP Project focused on assessing the solar heating systems value chain and all the components of the solar thermal heating system manufactured in Egypt, through conducting a survey of the current potential manufacturers in solar thermal technologies and their components in Egypt. It aimed at developing the local existing manufacturing of the solar thermal heating systems and to encourage the engagement of SMEs aiming at creating job opportunities within a green industry-based economy.

As a part of the roadmap implementation, best practice manual in manufacturing the solar water heating system main components is developed. The best practice manual is divided over 6 sections as follow;

Section 1: Introduction to Solar Water Heating System (SWH)

Introducing general solar energy aspects. In addition to introducing different solar water heating systems; presenting classification of solar water heating systems according to application, working temperature and working fluids.

Section 2: SWH Value Chain, Recommended Raw Material and Needed Manufacturing Processes

Illustrating the solar water heating system value chain including main components and accessories. The recommended raw material per each component of the SWH system. Finally, the needed manufacturing processes to achieve SWH system with high quality.

Section 3: Manufacturing of SWH System Components

This is considered the main section of this best practice manual. Firstly, it starts with determining the right selection of solar water heating technology according to different situations. Secondly, illustration of the manufacturing steps of main SWH components. The manufacturing steps includes description about process, machines needed, raw materials, level of labours and type of operation.

Section 4: General Organization for SWH Manufacturing

Focusing on the organization of SWH manufacturing facility aimed at optimizing manufacturing time. In addition to facilitating handling process of materials during manufacturing processes.

Section 5: In-house checks for R&D and QA

Focusing on illustration of the required tests to ensure high quality of locally produced SWH system components. These tests are recommended to be done in-house within the manufacturing facility.

Sections 6: General Tips (After Sales)

Considering after sales of the SWH systems installed within certain application. Only some general tips are illustrated.

Manual Guide

This manual represents the best practice in solar water heating system main components manufacturing. This best practice manual includes 6 sections to facilitate access of information within the manual.

Section No.	Topic
Section 1: Introduction to solar water heating system (SWH)	Solar Energy Concepts
	Collector Orientation
	Collector Solar Energy Definition
	SWH technologies Overviews
	SWH System Classification
	Solar Thermal Collector Classification
	Heat Transfer Medium
	Key Suitable Technologies for Egypt
	Calculation of Energy Produced by SWH System
Section 2: SWH Value Chain, Recommended Raw Material and Needed Manufacturing Processes	SWH Value Chain Components
	Storage Tank Definition
	Flat Plate Collector (FPC) Definition
	Evacuated Tube Collector (ETC) Definition
	SWH System Auxiliaries
	SWH System Cost Structure Breakdown
	Recommended Raw Material per SWH Component
	Needed Manufacturing Processes Per SWH Component
Section 3: Manufacturing of SWH System Components	Selection of Right Technology & Raw Material
	Sequence of SWH System Main Manufacturing
	Manufacturing of SWH Storage Tank
	Manufacturing of Flat Plate Collector
	Assembly of Evacuated Tubes General Tips
	Manufacturing of Mounting Structure
Section 4: General Organization for SWH Manufacturing	Required Manufacturing Areas
Section 5: In-house checks for R&D and QA	Exposure Test
	Exposure Test + External Shock
	Exposure Test + Internal Shock
	Mechanical load
	Final Inspection
	Analysis of Inspection after exposure and shocks
Section 6: General Tips (After Sales)	After Sales of SWH System General Tips

Section 1: Introduction to Solar Water Heating System Manual Guide

1.1. Introduction

In this section general solar energy aspects will be introduced as well as different solar water heating systems. In addition to presenting classification of solar water heating systems according to application, working temperature and working fluid.

1.2. Solar Energy Concepts

Solar energy is related to Sun and Earth; each has its own characteristics and parameters affecting amount of solar energy reaching the earth's surface.

Sun is considered the main source of energy in the universe. It has a surface temperature approximately of 5,505 ºC. While the irradiance is approximately 1,368 W/m^2.

Earth orbits around the sun describing an ellipse in 365 days and ¼. The earth orbits around its own axis in 24 hours.

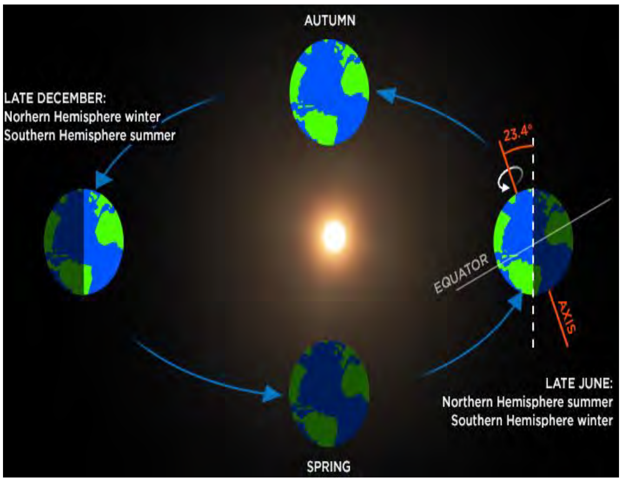


Figure 1 Earth's orbit around the sun

Table 1 Characteristics of Sun

Principal characteristics of Sun	
Constitution	Helium (74%) Hydrogen (24%)
Average diameter	1,392,000 km (12,000 km for earth)
Mass	301,9891 x 10^{30} kg
Distance/Earth	150,000,000 km
Life expectancy	5 ^10 milliards years
Actual age	4,5 milliards years

Solar energy terms definition:

Table 2 illustrates solar energy terms and the corresponding units definition. A clear and sunny day anywhere on earth has average Irradiance of 1,000 W/m^2 and Irradiation of 8 kWh/m^2.

Table 2 Solar energy definition

Term	Definition	Unit
Irradiance (G)	Radiant flux received by a surface per unit area. (**Power**)	W/m^2
Irradiation (H)	The total quantity of energy incident on a surface. (**Energy)**	kWh/m^2
Solar irradiation	The quantity of solar energy incident by the collector in a certain time.	kWh/day or kWh/year
Specific solar irradiation	The quantity of solar energy incident by 1 m^2 of collector surface in a certain time	kWh/m^2/day or kWh/m^2/year

Example1:

- The solar power incident on a surface average 400 W/m^2 for 12 hours. How much solar energy is received?

  $$400\ W/m^2 \times 12\ hours = 4{,}800\ Wh/m^2 = 4.8\ kWh/m^2$$

- The amount of solar energy collected on a surface over 8 hours is 4 kWh/m^2. What is the average solar power received over this period?

  $$4\ kWh/m^2/8\ hours = 0.5\ kW/m^2 = 500\ W/m^2$$

Components of solar radiation

The total radiation is composed of three components as follow;

- Direct Radiation: ➔The radiation coming directly from the sun
- Diffused Radiation: ➔The radiation diffused by the sky, layers of atmosphere and other surroundings
- Reflected Radiation: ➔The radiation reflected back by the lake, seas and other water bodies

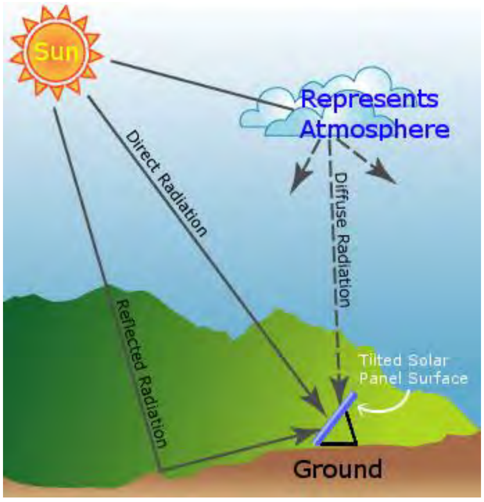


Figure 2 Type of solar radiation

Geometry of the sun height

- Sun average height: 21 mars / September = 90° - latitude
- Sun maximum height: 21 June = 90° - latitude + 23.5°
- Sun minimum height: 21 December = 90° - latitude – 23.5°
- Collector average tilt angle = latitude

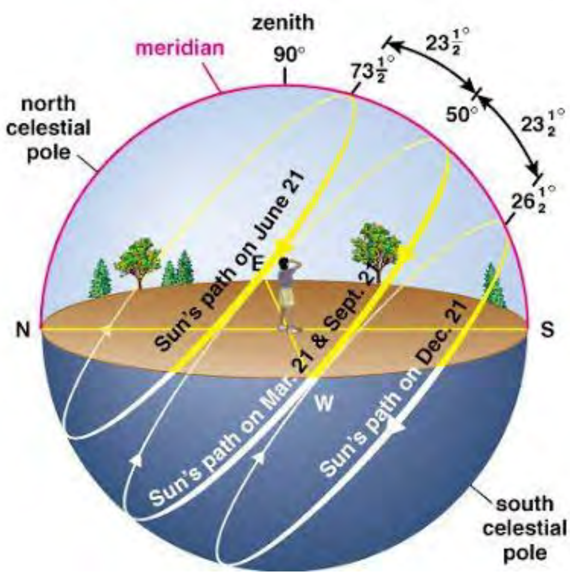


Figure 3 Sun path and height

1.3. Collector Orientation

Solar collectors' orientation is defined by three angles with respect to the earth's surface. These angles are important to describe the collector position with respect to Sun,

Figure 4:

- **Collector azimuth angle** represents the angle between geographic south and the collector faces direction.
- **Collector tilt angle** represents the angle between the array surface and the horizontal plane.
- **Solar incidence angle** represents the angle between the sun's rays and the normal (perpendicular) to a collector surface.

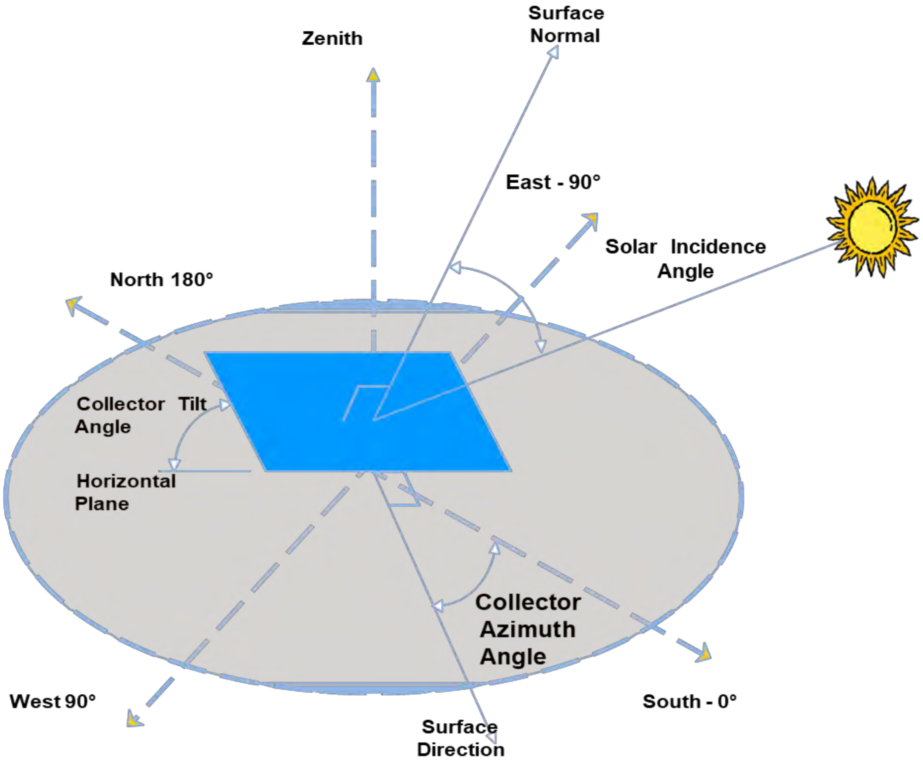


Figure 4 Collector main angles

Solar irradiation depends on collector orientation. This means that the collector surface must face south which means that the Azimuth angle is 0°. If the collector is facing another direction, the total incidence irradiation energy could be decreased by 40 % approximately.

Optimum of azimuth and collector tilt angle

- In the Northern Hemisphere, the optimal orientation is facing south: Azimuth 0°
- Optimal collector tilt angle = latitude angle
- Optimal collector tilt angle depends on the time of the year during which hot water is needed

Example: Cairo case

- Latitude: 30° - Optimal collector tilt angle: 30°
- Azimuth: 0°

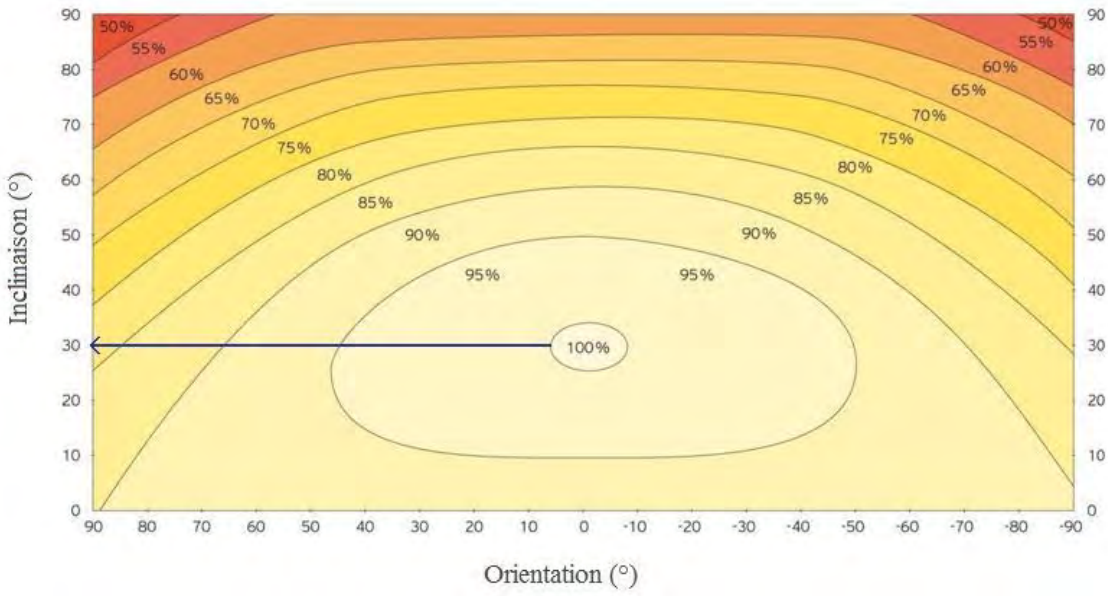


Figure 5 Optimum inclination and orientation angles for Cairo

1.4. Collector Solar Energy Definition

Total incidence irradiation energy received at the collector surface is not totally transferred to the working fluid. The total irradiation energy (E_0) is divided into three parts as follows:

- **Optical energy losses (E_1):** due to glass cover type.
- **Thermal energy losses (convection & conduction (Q_1, Q_2):** due to temperature different with respect to ambient temperature.
- **Usable energy fraction (Q_3):** used to working fluid heating.

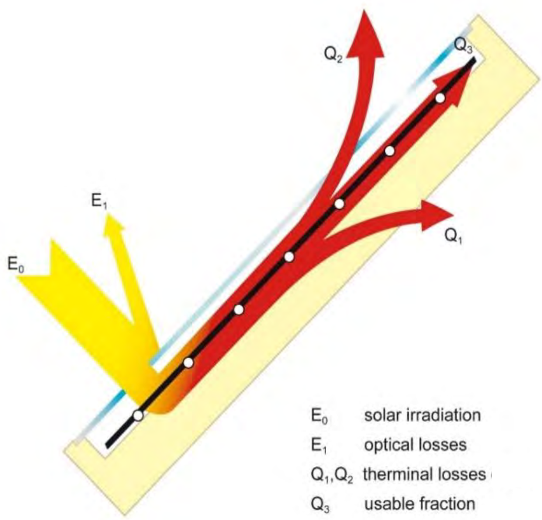


Figure 6 Schematic diagram for absorbed energy in solar collector

1.5. SWH Technologies Overview

This section represents the key SWH technology suitable for each sector. The precise selection of the SWH technology is a must in order to undo previous SWH bad reputation in Egypt. Nowadays a wide range of well-established solar thermal collector technologies deliver heat starting at low temperature range T < 80 °C, medium 80 °C < T < 150 °C up to high temperatures > 150 °C. This section presents the most commonly used solar thermal technologies and systems available in the market that cover the low and medium temperature range, which are suited for residential use (hot water and space heating), industrial process heat and hot water for commerce and services. High temperature collectors are available for CSP applications mostly.

1.6. SWH Systems Classification

In the following section the most commonly used systems are described briefly. Existing SWH systems worldwide are mainly classified according to the following:

- Type of fluid circulation: Thermosiphon and forced circulation systems
- Type of system configuration: Open and closed systems,
- Type of Heat transfer medium.

Thermosiphon (Natural Convection) Open Systems

Many small domestic SWH systems are so called gravity-driven systems such as Thermosiphon systems or integrated collector storage systems. These SWH systems depend on the scientific concept that warm water is lighter than colder water and the natural convection in the collector when it is not installed horizontally. In the case of Thermosiphon systems, the tank is usually placed directly at the top of the collector or very close and slightly above. The heated water enters the tank at the top and colder water at the bottom then flows back to the bottom of the collector. As it does not need controllers and pumps, this system operates very efficiently and completely without electricity. Small Thermosiphon systems are the cheapest solar thermal water heating systems available.

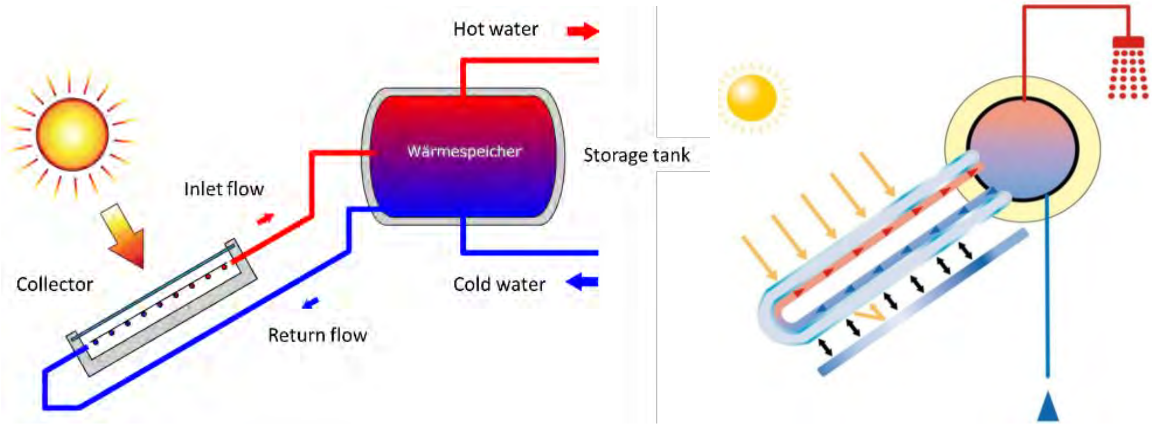


Figure 7 Functional diagram of a Thermosiphon open systems [1]

Thermosiphon (Natural Convection) Closed Systems

In closed system the heating fluid passing through the solar collector (supply side) is not the same as working fluid going to the application (demand side). This is the main difference between closed and open system. This separation is done through introducing middle component called heat exchanger. The heat exchanger could be inside or outside the storage tank and could be double jacket storage tank or embedded storage tank with heat exchanger.

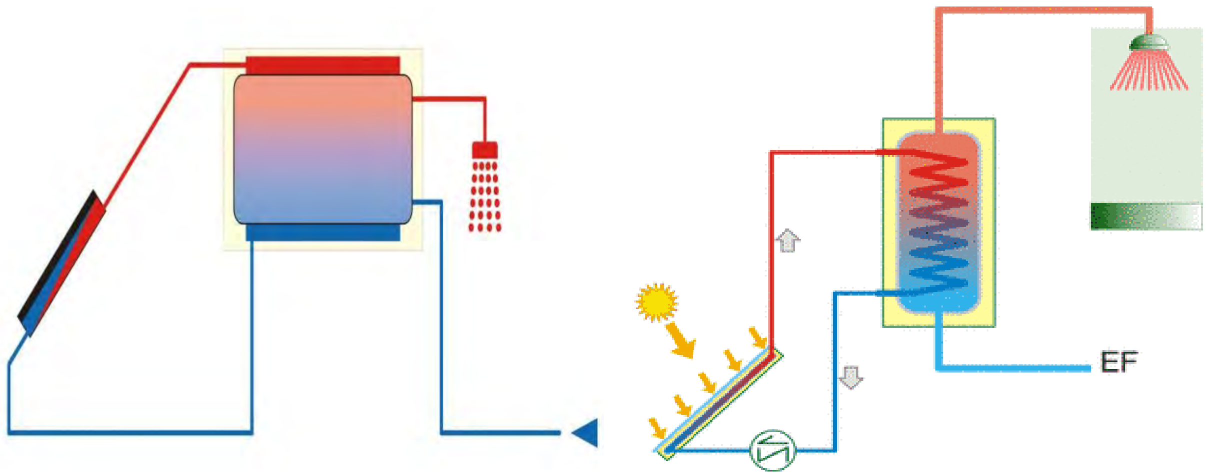


Figure 8 Functional diagram of thermosiphon closed systems

Forced Circulation Systems

Forced circulation systems use sensors and a controller to determine when a pump is to circulate the heat transfer fluid (HTF) through the collector. If the temperature in the collector is higher than that in the tank and if the temperature in the tank is still below boiling point, the pump is switched on to transport the heat from the collector to the tank. Forced circulation systems are more complex but allow more flexible system design, e.g. The tank can be placed below and further away from the collectors.

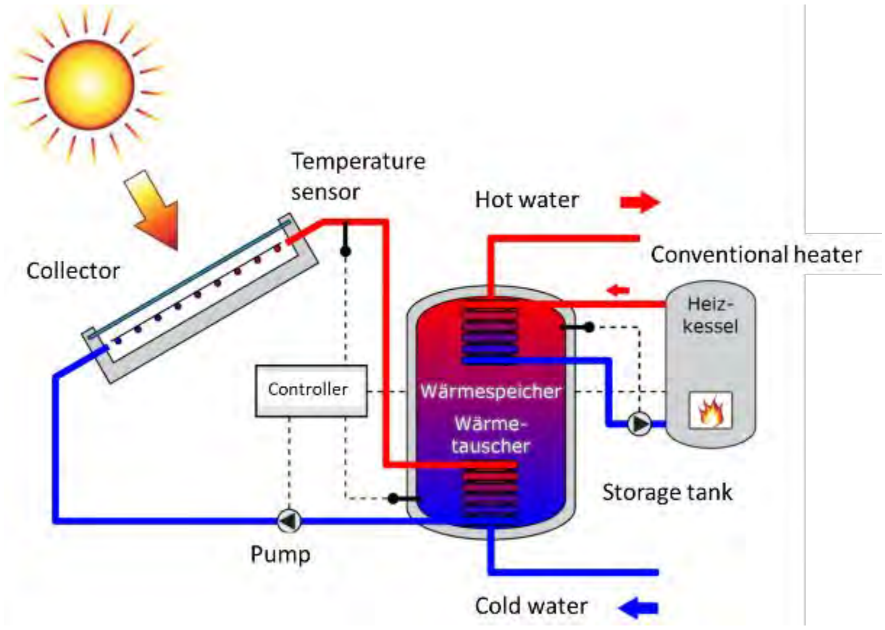
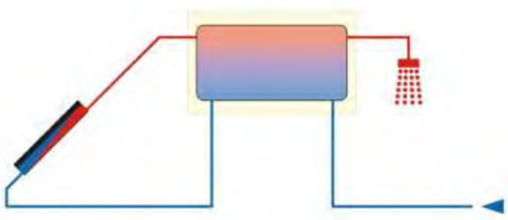
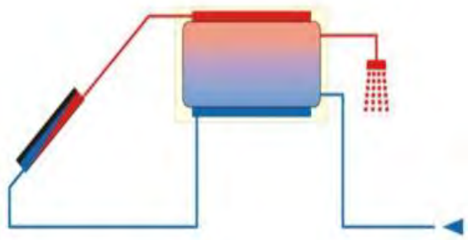
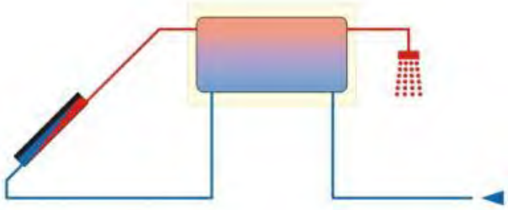
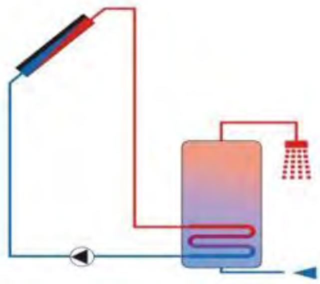


Figure 9 Functional diagram of a forced circulation system [1]

Thermosiphon System Comparison:

	Open Loop system	Close Loop system
		
ADVANTAGES	No heat exchanger needed Simple Low temperature losses No need expansion tank	Reduced limestone in the tube Hygienic No corrosion
DISADVANTAGE	Corrosion Limestone in collector Hygienic problem in water	Need a heat exchanger Need an antifreeze More expensive High temperature losses

Comparison Between Thermosiphon and Forced Circulation:

	Thermosiphon	Forced circulation
		
ADVANTAGES	No water pump No control system No electricity supply Simple and independent	Independent location Ability to separate tank- collector Large scale system possible Storage tank protected inside
DISADVANTAGE	Storage above the collector Storage outside For small capacities Bad system optimization	Need a pump Need a control system Need a supply electricity System interrupted during an electricity shut off

1.7. Solar Thermal Collector Classifications

The basic functionality of a solar thermal collector is the conversion of solar irradiation into heat. This happens when the sun heats the absorber of the solar collector, which is connected to a hydraulic circuit to transport the heat transfer medium (HTF) to a heat sink (heat storage, heat exchanger or direct process). The various solar technology concepts are based on different approaches to deliver heat at the desired operating temperatures.

1.7.1. Collector Characterization

The performance of a solar collector depends on its thermal and optical behavior determining the amount of irradiation that is effectively transformed into useful heat. Therefore, losses can be classified into;

- **Optical Losses,** which depend on the glass transparency and absorber surface absorptivity

- **Thermal Losses,** which depend on the insolation and the temperature difference between absorber and ambient.

In order to avoid these losses, several different technologies, components and materials have been developed throughout the years leading to more efficient collectors. The performance of a collector is described by an efficiency curve, Figure 10, which depends on the operating temperature, the ambient temperature and the total irradiation.

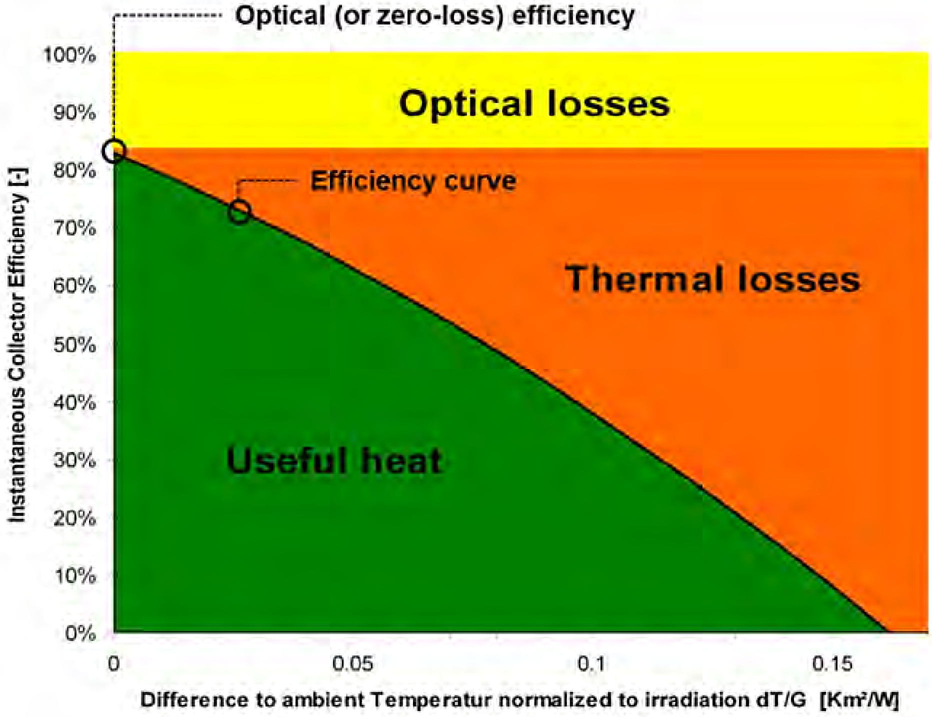


Figure 10 Solar collector efficiency curve

1.7.2. Stationary Collectors

Stationary (non-tracking) collectors are used traditionally for hot water or space heating purposes in the residential sector for low temperature range. These collectors do not use optical concentration and mounted stationary at one position.

- **Unglazed Collectors**

Figure 11 Collector AS, Energie Solaire SA

Unglazed collectors are not insulated. They are mainly used for swimming pool heating. Consist of black colored matting, tubes made from rubber, or plastic based materials through which the pool water is circulated. There are also some manufacturers using selective absorbers. These types of collectors warm up large amounts of water efficiently in sunny and warm weather conditions to temperatures below approx. 40°C. In sunny regions they can be used for domestic hot water supply.

- **Flat Plate Collectors**

Figure 12 Cobralino AK 2.8V, SOLTOP Schuppisser AG

Glazed Flat plate collectors are the most commonly and widely used type of solar thermal collector for domestic hot water applications in central Europe. A flat plate collector consists of an insulated box with an absorber sheet welded to a pipe that is filled with the heat transfer fluid. Flat plate collectors perform well to provide heat for basic domestic hot water use (< 60°C) in warm climates. However, high convective heat losses are an inherent disadvantage of the simple design. Due to the heat loss flat plate collectors are unable to deliver heat at higher temperature ranges (> 80°C), and the performance is significantly reduced at cold weather conditions.

- **Evacuated Tube Collectors**

Figure 13 OWR 20, AMK-Collectra AG

Evacuated tube collectors are the dominating technology in China. They are comprised of an array of single or double layer glass tubes with a vacuum that provides insulation against conductive and convective heat losses. Single wall evacuated tubes normally have a fin that has the absorber coating, similar to that used in the flat plate collector. Twin wall evacuated tubes have the absorber coating on the inner tube and the space between the two tubes evacuated. At higher temperature ranges (> 80°C) evacuated tubes work with higher efficiencies compared to flat plate collectors.

- **Photovoltaic Thermal (PVT) Hybrid Solar Collectors**

Figure 14 Hybrid 280/900 Sky, Meyer Burger AG

PVT collectors integrate photovoltaic and thermal solar energy conversion in a single device and thereby reach high yields per area. In situations where roof area is limited, and particularly in the light of new regulations requiring a part of buildings energy demand to be produced on site, PVT collectors provide an attractive option. Photovoltaic cells suffer from a decrease of efficiency with the rise in temperature. With the help of the thermal component, heat is carried away from the photovoltaic cells thereby cooling the cells and thus improving their efficiency by lowering resistance.

1.7.3. Tracking collectors

In order to achieve high operating temperatures (>100°C) in the collector, concentrating collectors focus the direct radiation component of the sun through mirrors onto a receiver. The collector must track the sun with one or two axes. The higher the solar radiation is concentrated, the higher the temperature that can be reached at the receiver. At the same time, the concentration factor increases the demand on the tracking accuracy. Suitable measures for minimizing heat losses (selective absorber coating, vacuum insulation of the receiver, insulation of the piping) are important, even with concentrating collectors, in order to achieve good efficiencies at high operating temperatures. The most common concentrating collectors are:

- **Parabolic Trough Collectors**

Figure 15 Parabolic trough collector, NEP

A parabolic-shaped mirror focuses the incident direct radiation onto a receiver tube in the focal line of the parabola. The receiver consists of an absorber tube, through which the heat transfer medium flows, which is usually concentric in a (possibly evacuated) glass tube, whereby the thermal losses of the absorber are reduced. The axis of the parabolic trough collector can be oriented arbitrarily. Typical types of this collector type have a length of a few meters and an aperture width of 0.5 to 2 m. It can heat water up to 400 °C.

- **Linear Fresnel Collector**

Figure 16 Fresnel collector, Soltigua

Several mirror rows (primary mirrors) are arranged in parallel and each is tracked uni-axially to focus the direct radiation onto a stationary receiver. The receiver consists of a tube bundle or a single absorber tube, which is enveloped by a (possibly evacuated) glass tube and, if necessary, supplemented by a secondary mirror. The secondary mirror reflects radiation from the primary mirrors to the rear of the absorber. In comparison to parabolic troughs Fresnel collectors achieve only lower efficiencies. However, they have the advantage of achieving a larger aperture area per receiver with lower wind loads and generally better space utilization. It can heat up water up to 250 °C.

- **Scheffler Dish Collector**

Figure 17 Scheffler mirror

Scheffler collectors use concentrating dish fix focus reflectors, which are tracked bi-axially. The tracking axis for the hourly movement is mounted parallel to the Earth's axis and passes through both the focal point and the center of gravity of the mirror. As a result, the focal point remains stationary (fixed focus), you can move the mirror with little force and the second axis only has to correct the seasonal change of the declination angle. Scheffler mirrors are very successfully used e.g. in India for steam generation in large community kitchens. It can heat water up to 200 °C.

1.8. Heat Transfer Medium

The following are some of the most commonly used heat-transfer fluids in the presence of heat exchanger (closed SWH system) and their properties [12]. These fluids are applicable for most of the applications depending on their availability in the local market.

Air will not freeze or boil, and is non-corrosive. However, it has a very low heat capacity and tends to leak out of collectors, ducts, and dampers.

Water is nontoxic and inexpensive, With a high specific heat and a very low viscosity. Although water is easy to pump unfortunately, water has a relatively low boiling point and a high freezing point. It can be corrosive if the pH (acidity/alkalinity level) is not maintained at a neutral level. Water with a high mineral content (i.e., "hard" water) can form mineral deposits in collector tubing and system plumbing.

Glycol/water mixtures have a 50/50 or 60/40 glycol-to-water concentration. Ethylene and propylene glycol are "antifreezes". These mixtures provide effective freeze protection as long as the proper antifreeze concentration is maintained. Antifreeze fluids degrade over time and normally should be changed every 3–5 years. These types of systems are pressurized, and should only be serviced by a qualified solar heating professional.

Hydrocarbon oils have a higher viscosity and lower specific heat than water. They require more energy to pump. These oils are relatively inexpensive and have a low freezing point. The basic categories of hydrocarbon oils are synthetic hydrocarbons, paraffin hydrocarbons, and aromatic refined mineral oils. Synthetic hydrocarbons are relatively nontoxic and require little maintenance. Paraffin hydrocarbons have a wider temperature range between freezing and boiling points than water, but they are toxic and require a double-walled, closed-loop heat exchanger. Aromatic oils are the least viscous of the hydrocarbon oils.

Refrigerant fluids or phase change fluids are commonly used as the heat transfer fluid in refrigerators, air conditioners and heat pumps. They generally have a low boiling point and a high heat capacity. This enables a small amount of the refrigerant to transfer a large amount of heat very efficiently. Refrigerants respond quickly to solar heat, making them more effective on cloudy days than other transfer fluids. Heat absorption occurs when the refrigerant boils (changes phase from liquid to gas) in the solar collector. Release of the collected heat takes place when the now-gaseous refrigerant condenses to a liquid again in a heat exchanger or condenser.

Figure 18 gives an overview of the most suitable collector technology for each process temperatures range in different industrial sectors. This figure indicates the residential and commerce sector as well. SHIP project roadmap focuses on low and medium temperature applications up to 90 °C by using ETC or FPC.

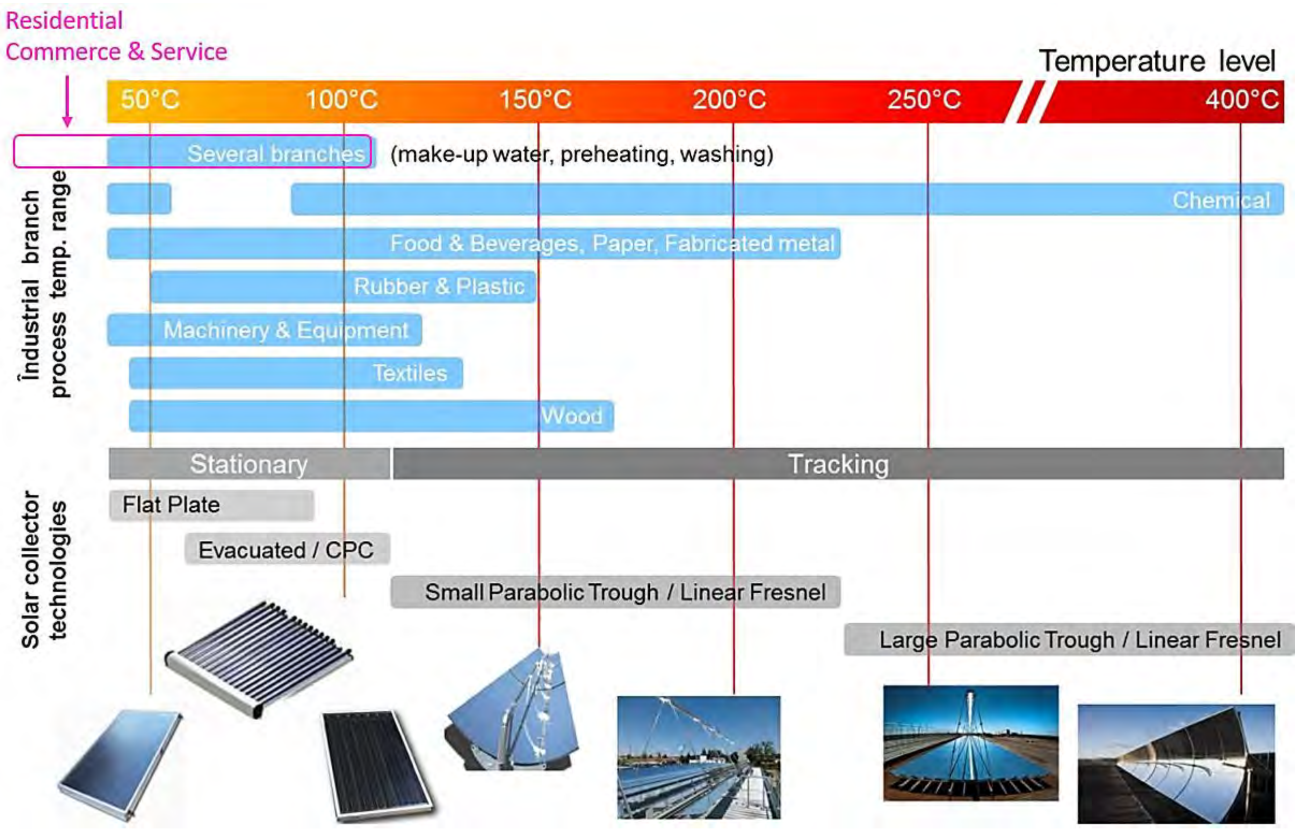


Figure 18 Overview of collector types based on their operating temperature and application in industrial, residential and commercial sectors (purple lines) [2]

1.9. Key Suitable Technology for Egypt

According to the developed national roadmap for manufacturing SWH system components locally in Egypt [2]. Some sectors have more than one key technology depending on the application within the sector. The assessment results are as follows:

- **Industrial Sector:** Low & medium temperature → ETC – Closed system – Forced
- **Residential Sector:** (1-4) families (Villas) → FPC – Closed system – Thermosiphon
  (5<) families (Buildings) → FPC/ETC – Closed system – Thermosiphon
- **Commercial Sector:** Hospitals, Malls & Schools → FPC/ETC – Closed system – Forced
  Hotels → FPC – Closed system – Thermosiphon
  → ETC – Closed system – Forced

The analysis shows that the Egyptian market would be best served by closed system due its robustness and capacity to perform well under various water quality and conditions. Consistency of water quality is a challenge for solar thermal systems sold in Egypt.

The collector type, whether flat plate collector or evacuated tube collector, is related to the application and level of temperature required by the demand side; while the system type, whether Forced system or Thermosiphon system, is related to demand flow rate and time response.

Mostly, the Thermosiphon system in Egypt is equipped with flat plate collector, while the forced system is equipped with evacuated tube collector.

1.10. Calculation of Energy Produced by SWH system

It is crucial for system design and system component manufacturing to be able to estimate the amount of energy produced by SWH system. Understanding these calculations will allow the manufacturer to figure the factors affecting the performance of the SWH system. These factors might be related to raw material selection, sizing of main components, technology selection. [3]

Figure 19 illustrate sample of SWH system that will be used as an example for energy analysis.

Definitions

- A_{col}: Collector area, m^2
- I: Intensity of solar radiation, W/m^2
- T_i: Inlet fluid temperature, °C
- T_0: Outlet fluid temperature, °C
- T_c: Collector average temperature, °C
- T_a: Ambient temperature, °C
- U_L: Collector overall heat loss coefficient W/m^2
- Q_i: Energy produced, W or kWh
- Q_u: Energy conversion, W or kWh
- Q_o: Energy loss, W or kWh

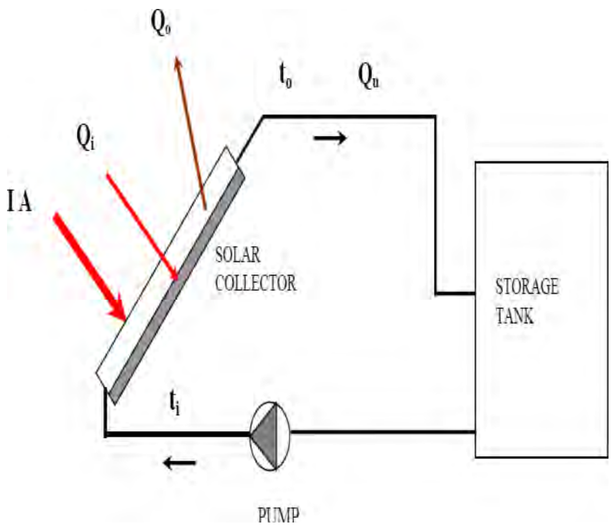


Figure 19 SWH system schematic diagram

Energy produced (Q_i)

The intensity of solar radiation, incident on the aperture plane of the solar collector having a collector surface area of $\mathbf{A_{col}}$ (m^2) then the amount of solar radiation received by the collector is:

$$\mathbf{Q_{sol} = I \,.\, A_{col}}$$

However, a part of this radiation is reflected back to the sky, another component is absorbed by the glazing and the rest is transmitted through the glazing and reaches the absorber plate as short wave radiation. Thus, the energy produced is:

$$\mathbf{Q_i = A_{col} \,.\, I \,.\, (\alpha.\, \mathit{t})}$$

With:

α: Absorption coefficient of plate

t: Transmission coefficient of glazing

Energy Loss (Q_0)

As the collector absorbs heat its temperature is getting higher than that of the surrounding and heat is lost to the atmosphere by conduction, convection and radiation. The rate of heat loss (Q_o) depends on the collector overall heat transfer coefficient (U_L) and the collector temperature. Thus, the Energy loss is:

$$\mathbf{Q_o = U_L \,.\, A_{col} \,.\, (T_c - T_a)}$$

Energy conversion (Q_u)

The rate of conversion energy extracted by the collector (Q_u), expressed as a rate of extraction under steady state conditions, is proportional to the rate of produced energy absorbed by the collector (Q_i), substracting the amount lost by the collector to its surroundings (Q_0):

$$\mathbf{Q_u = Q_i - Q_0}$$

Energy required ($Q_{required}$) is the amount of energy needed by the demand side. While **energy used (Q_{used})** is the amount of energy that is supplied by the SWH system. **Solar fraction** is factor that determine the ability of the SWH system to meet the required energy at the demand side.

$$\mathbf{Q_{used} = Q_{required} \,.\, Fs}$$

Where:

$$\mathbf{Q_{required} = \rho.V.C.(T_{hot} - T_{cold})}$$

V: Daily needed volume of water to heat per person

ρ: Density water (kg/m^3)

C: Heat capacity of water

Fs : Solar fraction of SWH system

C = 4186 J/kg•K = 4186 Ws/kg•K = 1,1628 Wh/kg•K = 1,1628 kWh/m^3•K

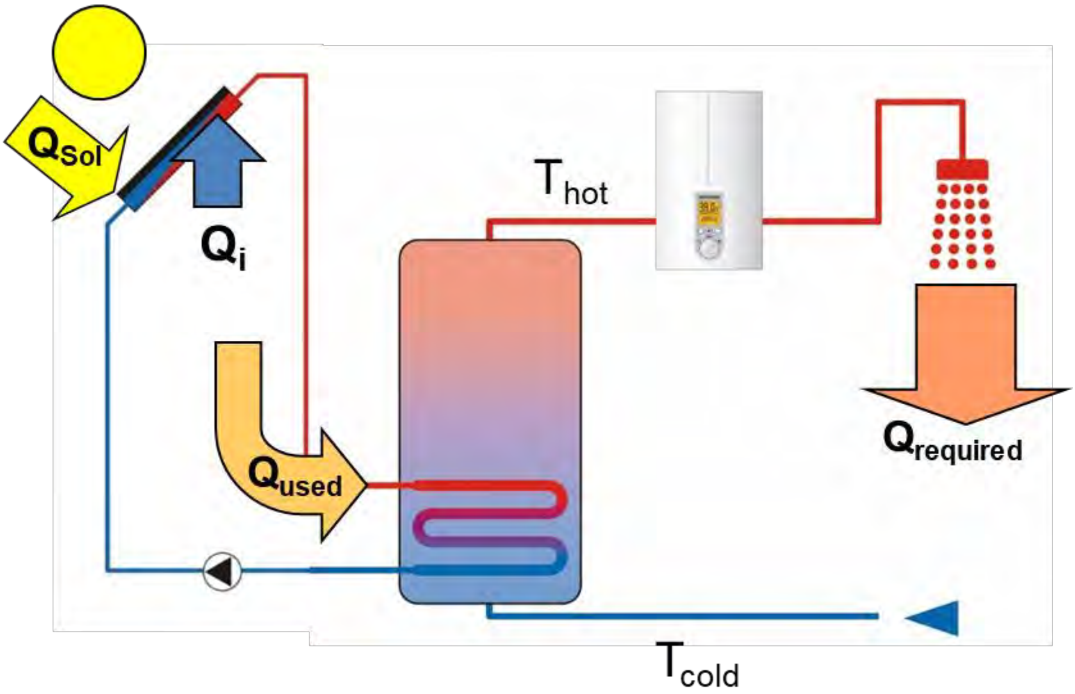


Figure 20 Schematic diagram of SWH system as example

Collector Efficiency (η_{col}) is representing the efficiency of solar collector to transfer input energy (Q_i) to used energy (Q_{used}). The collector efficiency depends on:

- Solar radiation
- Optic losses of collector glass cover,
- Thermal losses from the collector
- Temperature difference between collector surface and ambient temperature (T_c- T_a)

$$\eta_{col} = Q_{used}/Q_i$$

System Efficiency(η_{syst}) is the overall SWH system efficiency. It includes collector efficiency, storage efficiency and workpipe thermal efficiency. System efficiency is always lower than collector efficiency.

$$\eta_{syst} = \eta_{col} \cdot \eta_{storage} \cdot \eta_{pipe}$$

Collector area needed to satisfy the daily demand is depending on the SWH system efficiency and incidence solar radiation (I_{sol}) (kWh/day).

$$A_{col} = (Q_{used})/(I_{sol} \cdot \eta_{syst})$$

Figure 21 illustrate the relation between solar fraction and SWH system efficiency. It shows that solar fraction increases, when SWH system efficiency decreases, and vice versa. It is crucial to understand this chart for designing SWH system to be able to determine optimum number of solar collectors.

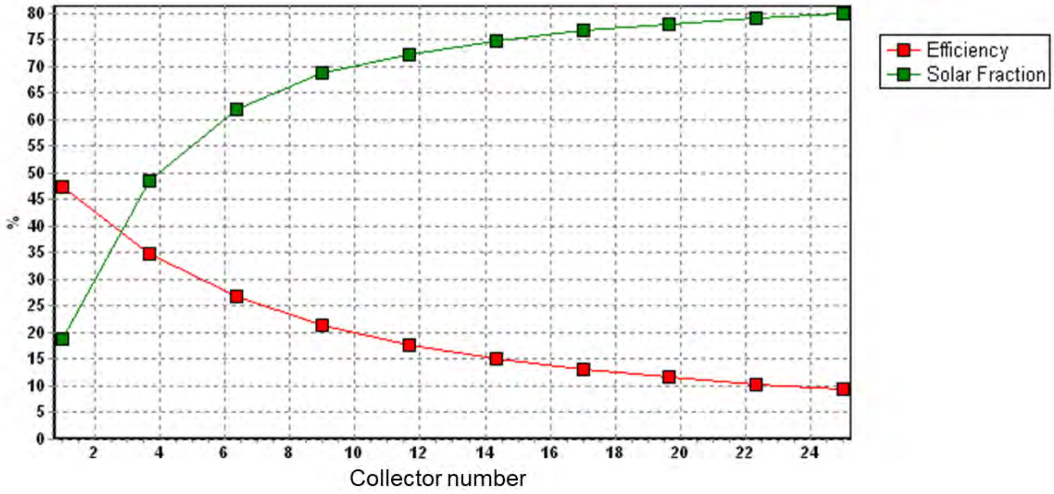


Figure 21 System efficiency vs Solar fraction

Examples on estimation of energy produced, see Annex 1:

- Estimation of energy required,
- Estimation of energy used,
- Estimation of energy input,
- Estimation of energy lost,
- Estimation of needed collector area,
- Estimation of needed storage volume.

Conclusion

- The solar radiation received on earth is affected by the earth's movements and atmospheric conditions.
- The irradiation depends on orientation and inclination
- The optimal orientation is facing south (**azimuth 0°**)
- The optimal collector tilt angle is the **latitude of the location**
- There are two SWH system types: Thermosiphon and Forced circulation (open and close loop)
- There are three types of collector technologies: Flat plate, evacuated tube and concentrated solar collector
- A good storage needs quality conditions
- The collector efficiency depends on different parameters
- The system efficiency depends on collector and tank efficiency
- **When the solar fraction increase, the system efficiency decreases and vice versa**
- **By increasing the collector surface, we increase the solar fraction and we reduce the system efficiency**

Section 2: SWH Value Chain, Recommended Raw Material and Needed Manufacturing Processes

2.1 Introduction

This section aimed at illustrating the solar water heating system value chain including main components and accessories. The recommended raw material per each component of the SWH system. Finally, the needed manufacturing processes to achieve SWH system with acceptable quality.

2.2 SWH Value Chain Components

SWH value chain components are divided into five main groups [1] identified as follow:

- Group 1: Metals group,
- Group 2: Non-metals group,
- Group 3: Coatings,
- Group 4: Auxiliaries,
- Group 5: Main components.

Non-Core Groups

Core Group

Non-Core Groups:

Group 1, metals group, is composed of all metal materials that are used in manufacturing SWH components. This group contain steel sheets with different thickness and surface roughness, stainless steel, aluminium (sheets and frames), and copper in form of tubes or sheets.

Group 2, non-metals group, is composed of non-metal material and items which are thermal insulation material and glass sheets with different transmissivity coefficient including low iron tempered glass.

Group 3, coatings, is composed of different coating materials used in the SWH systems. The SWH value chain contain three coatings:

- Internal coating: enamel coating **(for inner tank of storage tank and heat exchanger)**
- External coating: electrostatic coating **(for out tank of the storage tank)**
- Absorber coating: selective **absorber** coating, black Chrome or black-matt coating.

Group 4, auxiliaries, is mainly composed of control and fittings. Control consists of all the SWH system means of control (e.g. temperature sensor, pressure gauges, control cards, wiring, control platform), while fittings consist of all parts of the SWH system network and safety (e.g. piping, valves, pump, pressure temperature valve, relief valve, Mg rod, gaskets).

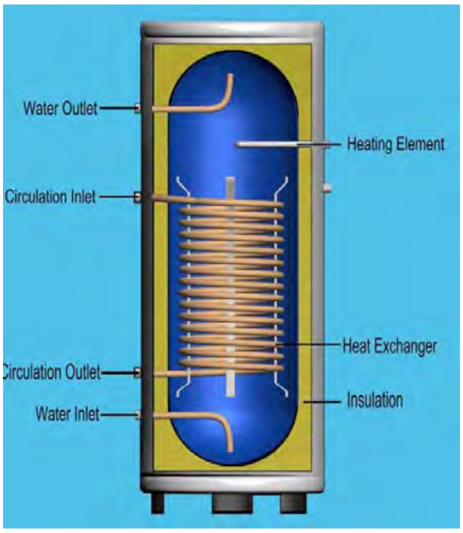
Core Group:

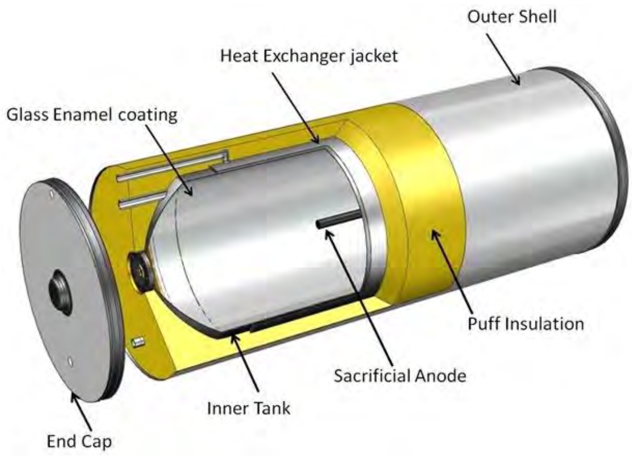
Group 5, main components, is composed of the core components of the SWH value chain, i.e. mounting structure, storage tank, flat plate collector (FPC) and evacuated tube collector (ETC).

Mounting structure supports the assembly of the storage tank with the collector, it should be well designed and it should withstand the outdoor conditions.

2.3 Storage Tank Definition

SWH system storage tank can be combined with internal heat exchanger in the closed SWH systems, or the heat exchanger can be separated from the tank as in the forced SWH systems. Storage tank equipped with heat exchanger have different configurations as shown in Figure 22. Storage tank consists of rolled steel sheets and welded with internal coating, then covered with insulation material which is shielded by rolled galvanized steel sheet.





a) Emedded coil b) Double jacket

Figure 22 SWH storage tank different configurations

2.4 Flat Plate Collector (FPC) Definition

FPC is the SWH system heart, it is responsible for absorbing solar radiation and transferring energy to the working fluid (most probably water or other alternative fluid according to the application). FPC simple definition illustration is a heat exchanger between Sun and working fluid. The assembly of FPC consists of back-sheet, thermal insulation, absorber (copper tube and fins), glass sheet and Aluminium frame, as shown in details in Figure 23.

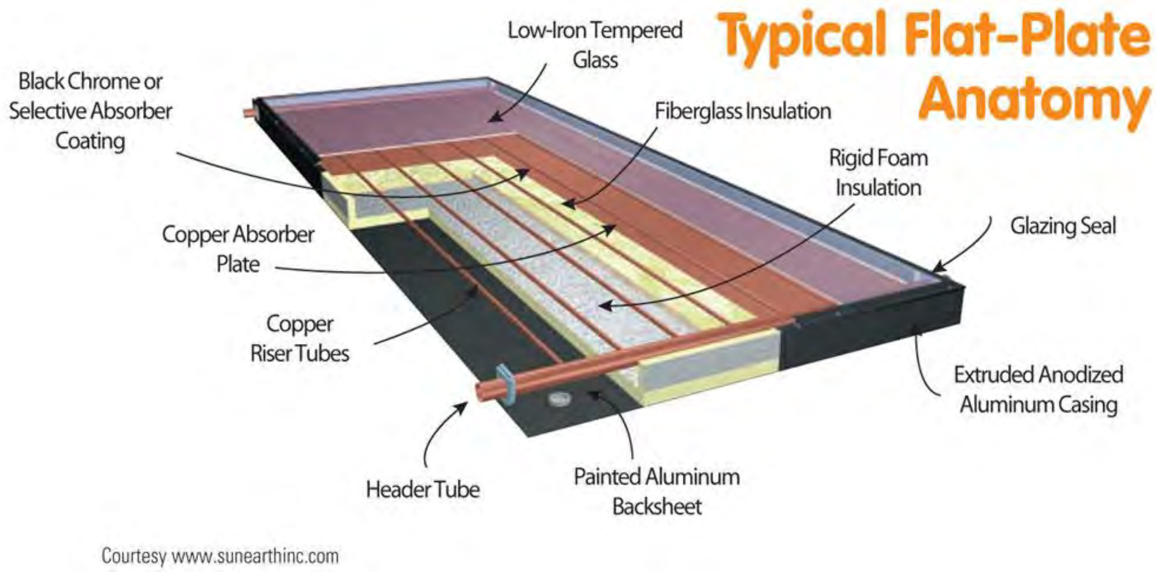


Figure 23 Flat plate collector typical breakdown components [9]

2.5 Evacuated Tube Collector (ETC) Definition

ETC is the last component in the SWH value chain, it is similar to FPC but uses a different configuration for absorbing solar radiation. Figure 24 shows the components used to assemble ETC, It consists of manifold and heat pipe (glass tubes, copper tube and absorber plate), as illustrated in Figure 24 and Figure 25.

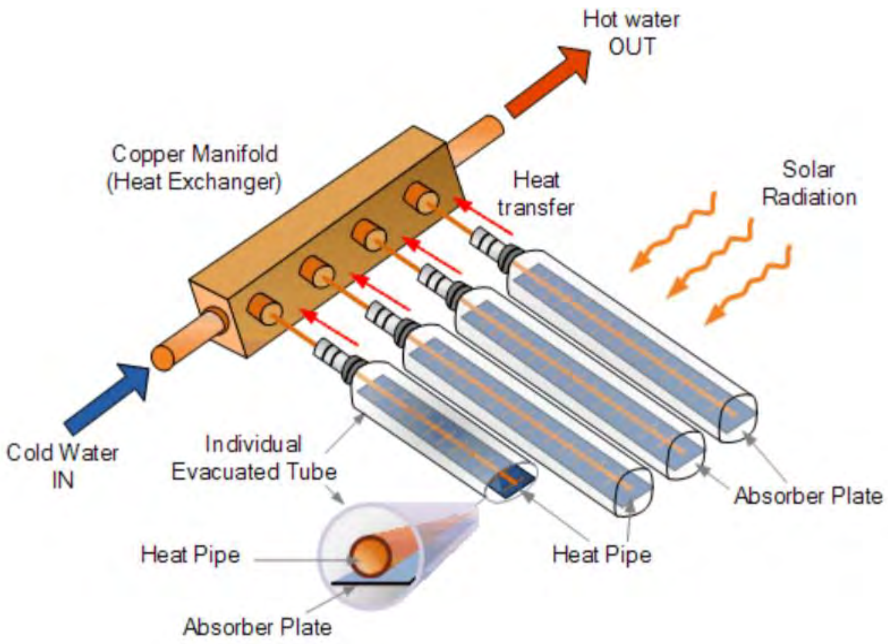


Figure 24 Evacuated tube collector typical breakdown components

The sun's radiation is absorbed by the selective coating on the inner glass surface, but is prevented from re-radiating out by the silver-coated innermost lining which has been optimized for infrared radiation. This acts similarly as a one-way mirror.

This is very efficient. 93% of the sun light's energy hitting the tube's surface, is absorbed, whereas only **7% is lost through reflection and re-emission**. The presence of the vacuum wall prevents any losses by conduction or convection. **Because of this, the system works even in very low temperatures, unlike traditional flat plate**

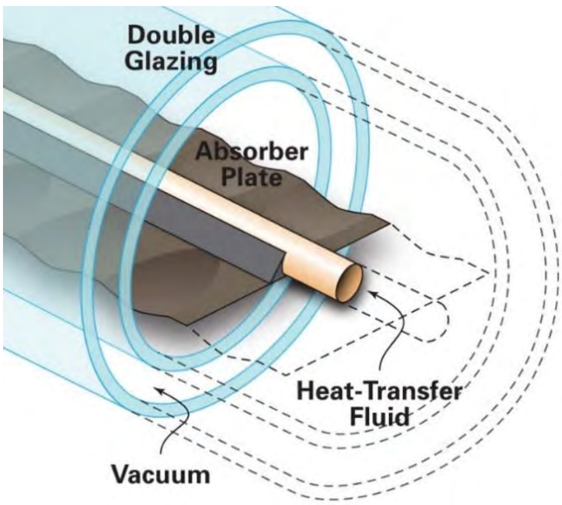


Figure 25 Heat pipe breakdown components

In the global market, the heat pipe has different configurations according to the manufacturer know-how and end-market application. The four different configurations, as illustrated in Figure 26, are as follow:

- Single glass heat pipe,
- Twin tube heat pipe (pressurized),
- Twin tube heat pipe (unpressurized),
- Twin tube heat pipe (Direct flow, unpressurized)

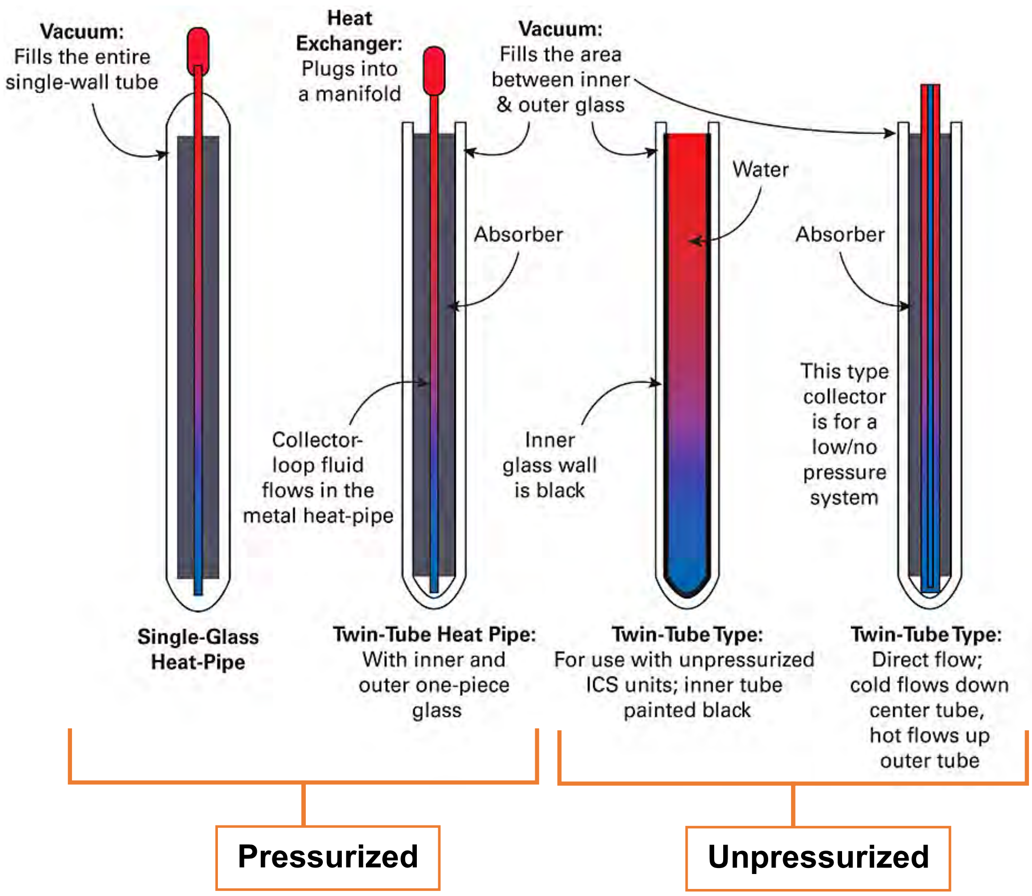


Figure 26 Heat pipe breakdown components

2.6 SWH System Auxiliaries

Solar water heating systems have auxiliaries. The most frequently used auxiliaries are: safety valve, Mg rod, electrical heater, expansion tank, coolant and connecting pipework.

Safety valve is protecting the individual SWH against overpressure. Its function is:

- Safety valve: evacuation of water in case of overheating,
- Check valve (Non return valve)
- Manual water heater drain valve
- Shutoff valve

Figure 27 Safety valves

Magnesium Anode (Mg rod) is preventing corrosion in the storage tank increasing life time of the SWH system. Otherwise leakage will occur after few months of operation depending on the water quality.

Figure 28 Mg rod

Electrical heater (Backup system) is an electrical resistor used as a heating supplement in case of insufficient sunshine or if the needs is higher than expected (backup system).

Figure 29 Electrical backup heater

Expansion Tank is another small tank that is attached to the water supply pipe of the SWH. The expansion tank is designed to handle the thermal expansion of water as it heats up in the SWH, preventing excessive water pressure (Overpressure). It is used in indirect and forced circulation system.

Figure 30 Expansion tank

Coolant (Heat transfer medium) is might be water or a mixture of water and glycol. It is used to enhance the heat transfer preventing fluid degradation by high temperatures. It will reduce the lime scale in the circuit. A mixture of 40 % glycol mixture provides frost protection down to -20 °C. It is used only for indirect and forced circulation systems.

Figure 31 Coolant mixtures

Connecting pipework is the piping system that connects between SWH system (supply side) and application (Demand side). It should have the following characteristics:

- Resist at high temperature and the corresponding pressures,
- The common material used is copper,
- Avoid use of galvanized steel,
- Plastic or multilayer tubes are prohibited for temperature higher than 70 °C,
- Insulation is fundamental for heat energy conserving,
- The insulation of the external pipes has to resist to UV light.

2.7 SWH System Cost Structure Breakdown

Best Practice guide will focus on manufacturing SWH system main components. This conclusion is based on the SWH system cost structure breakdown,

Figure 32, and on the capability of local labours and manufacturing processes. The main components that will be covered in the next sections are: storage tank, flat plate collector and Mounting structure.

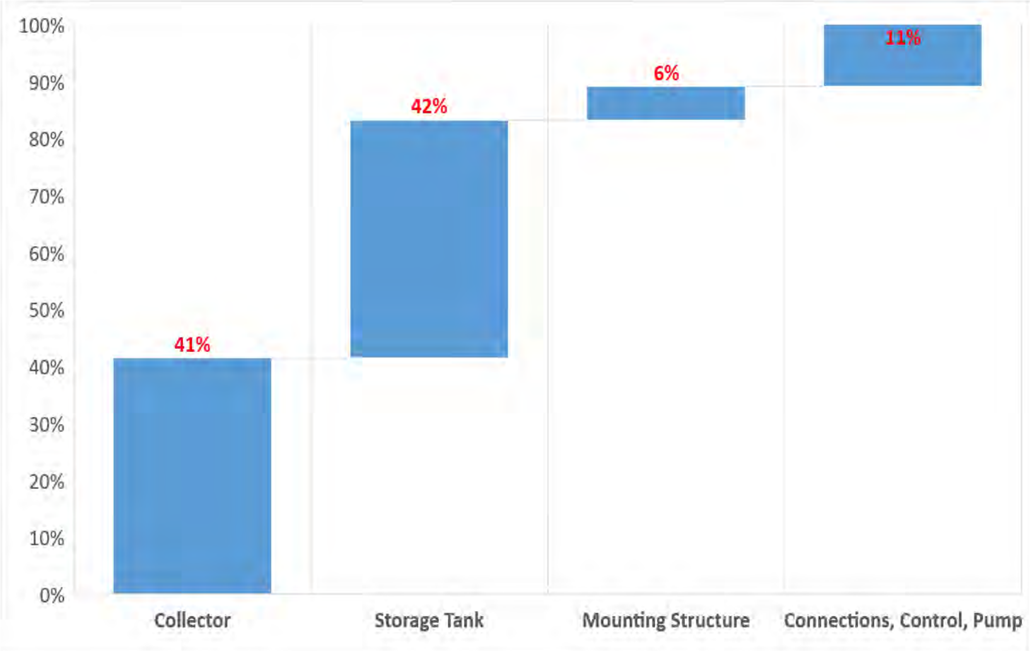


Figure 32 SWH system cost breakdown [1]

2.8 Recommended Raw Material per SWH Component

Each solar thermal collector type has its own characterization and maximum output temperature. As mentioned before, SWH systems can be divided into five groups, Table 3 identifies the required input material for each component according to core group (main components) and non-core groups (except auxiliaries).

Table 3 Required inputs of each main component in the system [1]

		Main Components			
		Mounting structure	**Storage tank**	**Flat plate Collector**	**Evacuated Tube collector**
Metals	Steel sheets	✓	✓		
	Stainless Steel Sheets		✓		
	Aluminium			✓	
	Copper		✓	✓	✓
Non -Metals	Insulation		✓	✓	
	Glass			✓	✓
Coatings	Internal Coating		✓		
	External Coating		✓		
	Absorber Coating			✓	✓

To summarize, the SWH value chain components and the linkages between the different groups of the SWH value chain are shown in Figure 33, which represents the feeding materials and components needed to manufacture complete systems of solar water heaters. Components with orange background indicate input materials, while components with light blue background are assembled by using the input materials.

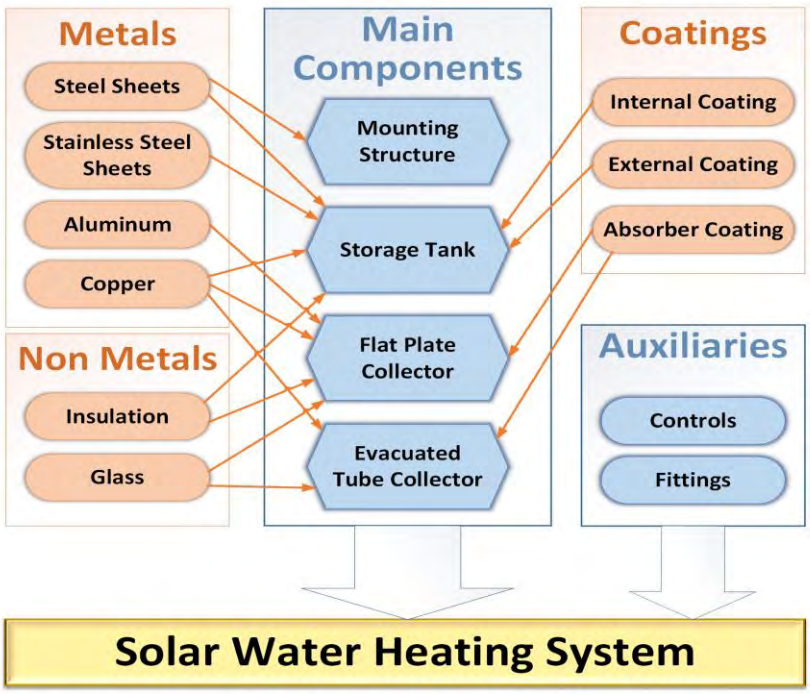


Figure 33 Value chain components of solar water heating system [1]

2.9 Needed Manufacturing Processes Per SWH Component

According to the national roadmap of manufacturing solar water heating system components locally in Egypt. Table 4 illustrates the required manufacturing processes as per main components of the SWH systems.

Table 4 Required manufacturing processes as per SWH main component [1]

		Main Components			
Process		**Mounting structure**	**Storage tank**	**Flat plate Collector**	**Evacuated Tube collector**
Machining		✓			
Stamping		✓	✓	✓	
Molding			✓	✓	✓
Pipe Bending			✓	✓	
Lase cutting			✓	✓	
Welding	Arc Welding	✓	✓		
	Laser Welding			✓	✓
Coatings	Enamel Coating		✓		
	Selective Coating			✓	✓
	Electrostatic coating		✓		
Punching			✓		
Rolling			✓		
Casting			✓		
Sandblasting			✓		
Evacuating					✓

Section 3: Manufacturing of SWH System Components

3.1 Introduction

This section is considered the main section of this best practice manual. At first, it starts with determining right solar water heating technology selection according to different situations. Then, illustration of the manufacturing steps of SWH main components. The manufacturing steps include process description, machines needed, raw materials, labours level and operation type.

3.2 Selection of Right Technology & Raw Material

In order to achieve high performance SWH system, It is important to select the proper material. Moreover, proper selection will affect the system lifetime.

In Egypt the main issue that affects the lifetime of SWH system is the water quality. Early in 1980's, Egypt took steps forward to install SWH system for domestic and touristic use. Unfortunately, this initiative didn't achieve its goals. **The reason was the wrong selection of technology that was not able to withstand the salinity of local water and the existence of Chlorine in local water**. Table 5 illustrates the different water quality effect on the SWH system and the recommended actions to be taken.

Table 5 Effect of water quality on SWH system [3]

Water Type	Cause	Action
Temporary hard water	Scale formation	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	Scale formation	Water could be pre-treated
Saline Water	Corrodes mild steel, galvanized piping as well as stainless steel	**Mild steel storage tank** can be used with proper treatment and paint protection
Acidic Water	Corrosive to mild steel, galvanized iron, copper and other metals. corrosive to stainless steel if the water contains sulphides, chlorides and fluorides	**Evacuated Tube Collector (ETC)** based systems should be used in such water conditions. However, such water quality is rare.
Alkaline Water	Galvanized iron starts losing zinc which deposits on copper surfaces in the same system	Insulated PVC pipes for **work-piping** may be used instead of GI pipes to avoid zinc depletion
Water with high turbidity	Solids will settle down slowly when the water stays for a long time in any container. These suspended solids are often charged particles.	If turbidity in water can't be avoided, **periodic maintenance** must be carried out for reliable and smooth operation of the system

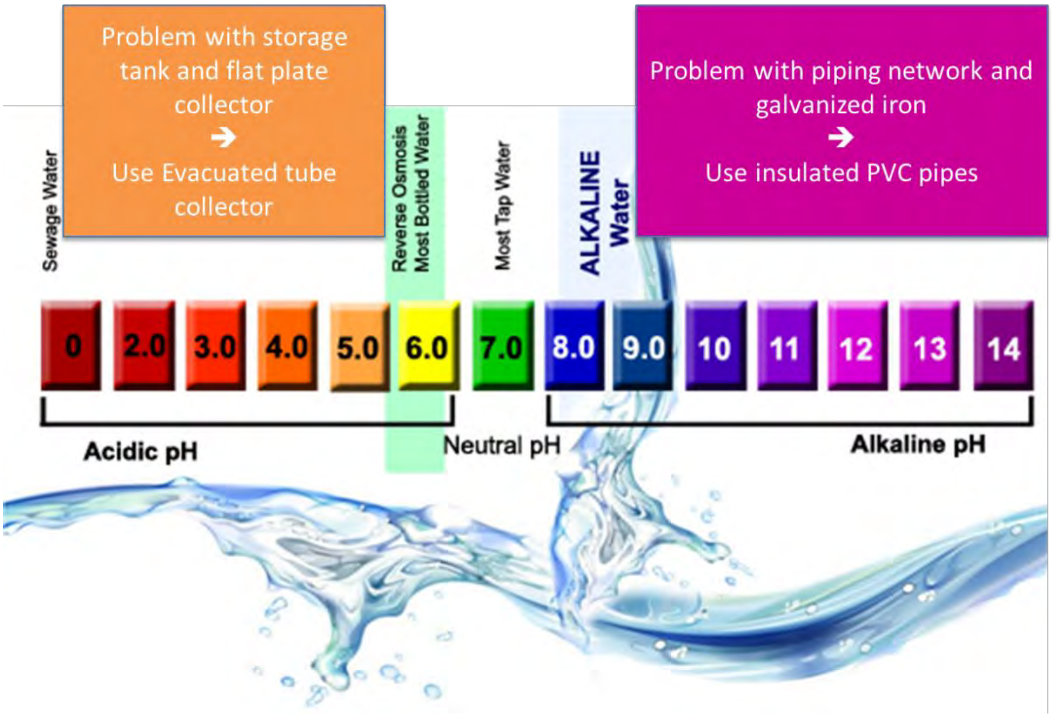


Figure 34 Water PH chart

3.3 Sequence of SWH System Main Manufacturing

To facilitate the way of illustration the manufacturing steps of main components of SWH system, previously main components were determined as: Storage tank, Flat plate collector, evacuated tube collector and mounting structure. In fact, this best practice manual will focus on manufacturing three components only: Storage tank, Flat plate collector and mounting structure. As well as assembly of evacuated tube collector with storage tank. The reason is that the assessment of the availability of skilled labor, availability of raw material and manufacturing capabilities shows that **Egypt has competitive edge in manufacturing Storage tank, Flat plate collector and mounting structure**.

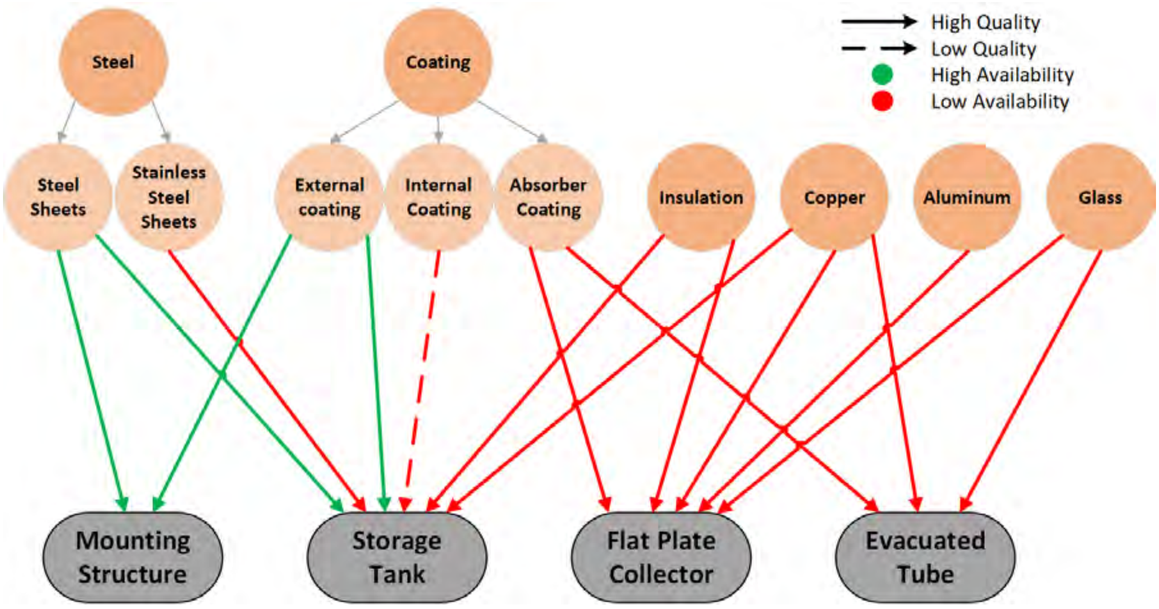


Figure 35 Value chain input assessment [1]

Combining the assessment of the manufacturing processes with the value chain components, Figure 36 shows that Egypt has high potential for mounting structure and storage tank local manufacturing with issue related to internal enamel coating and laser welding that need to be improved from the points of view of capabilities and availability of skilled labours; followed by local manufacturing of flat plate collector; while there is no competitive advantage in manufacturing evacuated tubes within the short term. These assessments were done in developing national roadmap for manufacturing of SWH system in Egypt.

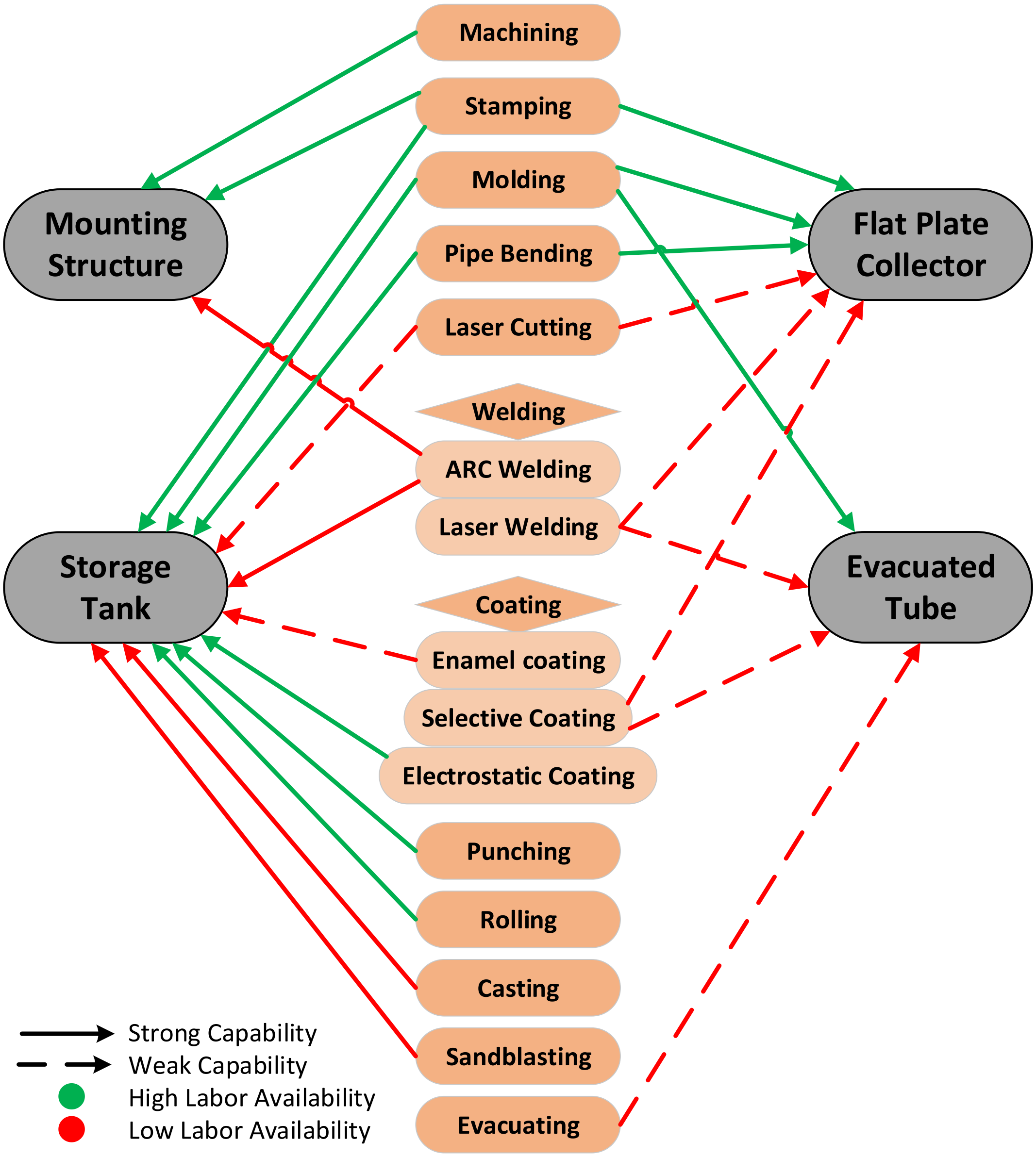


Figure 36 Assessment between SWH main components and manufacturing processes [1]

Manufacturing steps of the main components of the SWH system are divided into three production lines:

1. **Storage tank:** Inner tank, insulation and outer tank.
2. **Flat plate collector:** Absorber, insulation, Aluminium frame and glass sheet.
3. **Mounting Structure:** Steel angles, bolts and coating.

Manufacturing of main components of the SWH system is divided into main five areas: inspection of the raw material, manufacturing processes, assembly, quality control and packaging & traceability.

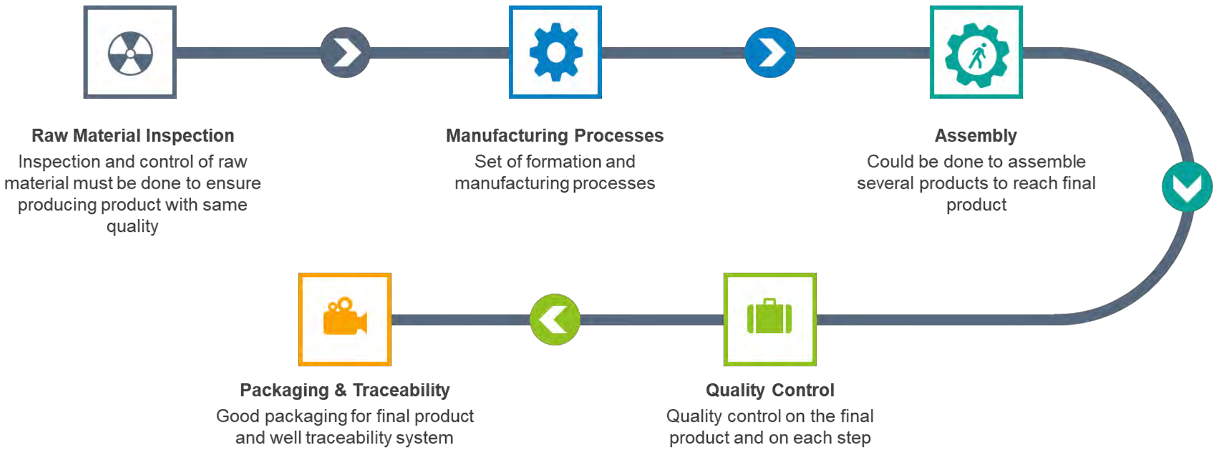


Figure 37 Manufacturing main five areas

In case of need for outsourcing any of SWH system components, it is crucial to follow below recommendations:

- Identify the **requirements for outsourcing** services or part of manufacturing,
- Select the **best partner for the outsourcing** services and **periodically** evaluating the quality,
- Accomplish responsibility of the outsourcing and identify the solution when a problem occurs,
- Plan and **implement auditing of the outsourcing** partner with the aim to check the quality system already implemented to guarantee the minimum quality required by the product,
- The **in-house R&D improvement** of any SWH component should be communicated to the outsourcing partner in order to share the same objectives between SWH manufacturer and outsourcing partners.

3.4 Manufacturing of SWH Storage Tank

SWH system storage tank consists of: inner tank, outer tank, thermal insulation, heat exchanger and accessories. These accessories are consisting of Mg rod, seal joint, barrel, Plastic cowl. Figure 38 **Plastic cowls** are used as two ends of the outer tank.

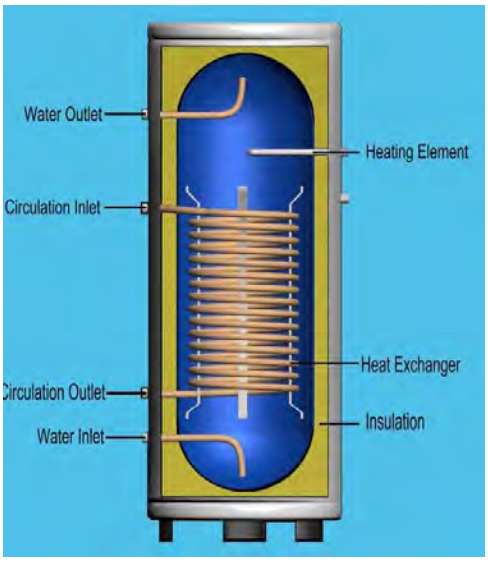


Figure 38 Sample of embedded coil storage tank

Mg rod is used to avoid inner tank corrosion. As the existence of dissolved salts in water can cause inner tank corrosion that will yield to leakage of heat transfer medium.

Joint seal is a sealing material the is used in between tank and barrel. **Barrel** is a Stainless-steel ring that fix all tank accessories.

Storage tank is used to ensure that the solar energy will match the required demand energy. Storage tank could be vertical or horizontal. Moreover, it could be equipped with heat exchanger for closed SWH systems. As well as, another heat exchanger could be used as auxiliary heating system.

Storage tank size could vary from 80 Litres to 3,000 Litres. Figure 39 illustrate different configuration of SWH storage tank that could be applied for vertical and horizontal tanks. Ideal storage tank conditions for SWH system are:

- Small storage volume (high specific heating capacity)
- Low heat loss (low volume/area ratio, good insulation)
- Good thermal stratification (means having a vertical tank)
- Design for a 25-year lifespan
- Ability to support the required temperatures and pressures
- Environmentally friendly tank material and heat transfer fluid.

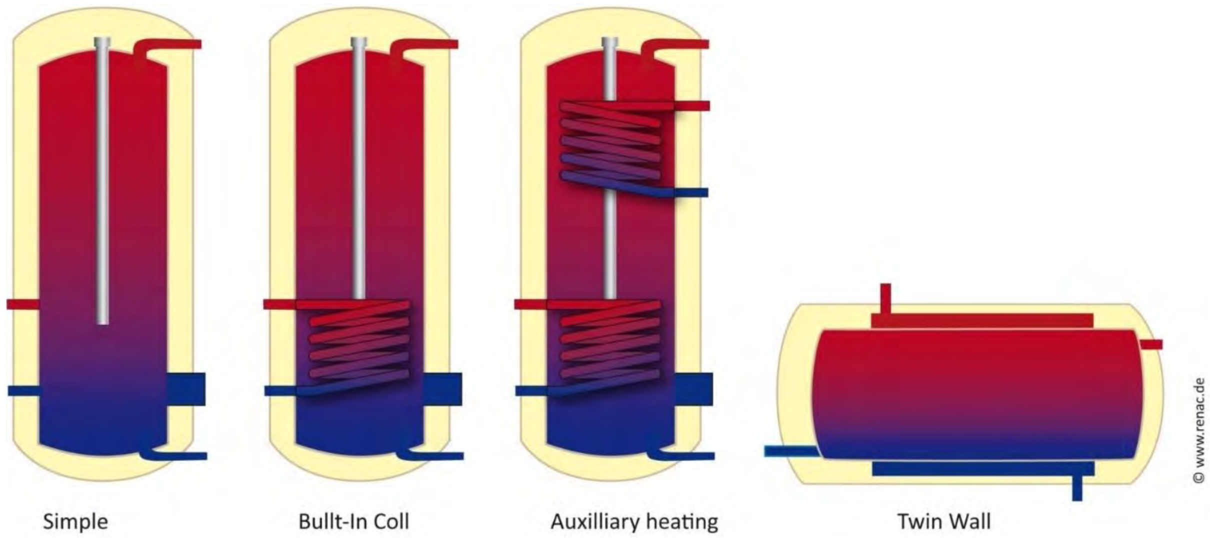


Figure 39 Different storage tank configurations

Manufacturing SWH storage tank follow **three stages**:

- Steel identification and selection,
- Steel transformation (from cutting to blasting),
- Assembling and finishing.

Flow chart for storage tank manufacturing processes, Figure 40, **consists of main 17 steps**. Later in this section, each step description illustration. Also, determination of needed quality control in each manufacturing part.

Table 6 Required inputs of SWH storage tank [1]

		Main Components			
		Mounting structure	Storage tank	Flat plate Collector	Evacuated Tube collector
Metals	Steel sheets	✓	✓		
	Stainless Steel Sheets		✓		
	Aluminium			✓	
	Copper		✓	✓	✓
Non -Metals	Insulation		✓	✓	
	Glass			✓	✓
Coatings	Internal Coating		✓		
	External Coating		✓		
	Absorber Coating			✓	✓

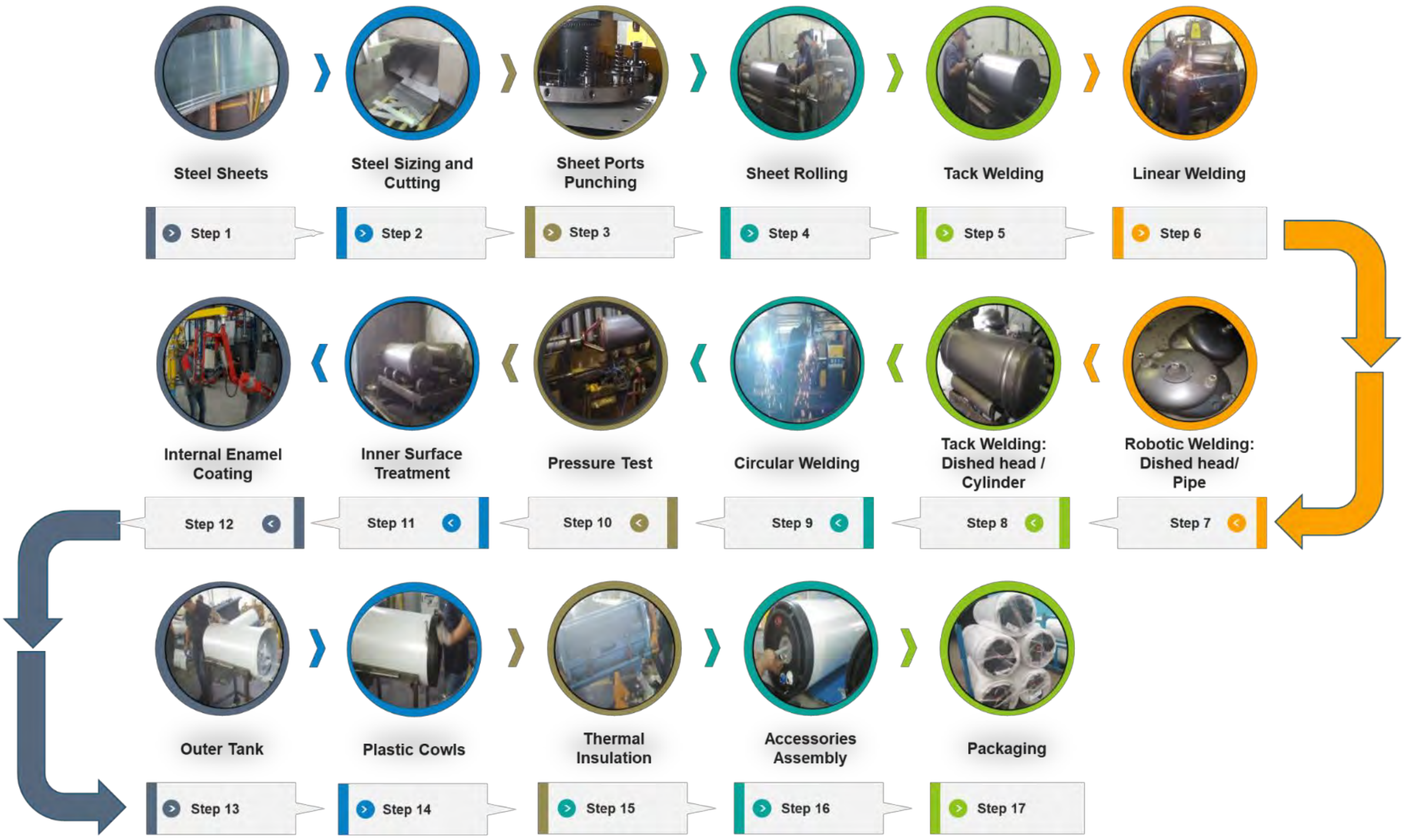


Figure 40 Flow chart of storage tank manufacturing process

3.4.1 Inner Tank

Step 1: Steel Sheets

Steel identification and selection: Mild or black steel is the most commonly used material for the storage tanks, as it has the strength for the pressure requirements (6 bars or more). The thickness is around **2 mm for cylinder and 3mm for dishes**. It has to be especially for enameling.

The mild steel must have low carbon percentage (between 0.05% and 0.15%). The low carbon makes the steel quite malleable and can be easily bent, rolled and welded into desired shapes. This flexible quality makes it easy to form the basic “curved bottom” assemblies that are used to create many finished storage tanks from steel plates.

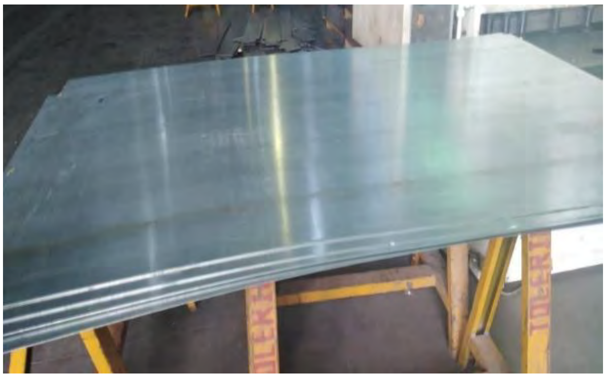


Figure 41 Mild steel sheets

Step 2: Sheet Cutting and Slitting

Sheets coil for tank body are cut into the require dimensions using slitting machine as shown in Figure 42. This process can be done using plasma cutting process.

- **Process:** Slitting & Shear Machine
- **Material:** Low Carbon Steel
- **Sizes:** Depends on required tank size
- **Thickness:** 2 - 3 mm
- **Operation:** Automated, Semi-automated or Manual
- **Quality Control:** Periodic and systematic maintenance of the machine is a key factor for quality

Figure 42 Inner tank sheet cutting [3]

Step 3: Sheet Ports Punching

After cutting process, holes for inner and outer pipes and accessories are punched in tank body using punching machine (ex, CNC machine). As well as holes for evacuated tubes in case of using evacuated tube collector as shown in Figure 43.

- **Process:** Punching
- **Sizes:** Depends on required fittings
- **Operation:** Automated or Semi-automated
- **Quality Control:** Periodic and systematic maintenance of the machine is a key factor for quality

Figure 43 Ports punching in tank body [4]

Step 4: Sheet Rolling

After cutting, the sheet is rolled using rolling machine for forming the circular shape of the tank as shown in Figure 44.

- **Process:** Rolling
- **Operation:** Automated, Semi-automated or Manual.
- **Quality Control:** Qualification of personal is a key factor for quality of rolling

Figure 44 Tank body rolling [4]

Step 5: Tack Welding

After rolling, the sheet is tacked welding the cylinder with a MIG welder (Metal Inert Gas) as shown in Figure 44. Tack welding used to keep roundness of rolled sheet before linear welding

- **Process:** MIG welder
- **Operation:** Manual.
- **Quality Control:** Qualification of personal is a key factor for quality of track welding

Figure 45 Tack welding [3]

Step 6: Sheet Welding

The two edges of the rolled sheet are then **welded** together, Figure 46. There are another types of welding that can be used but arc welding is considered the best practice type. Arc welding is preferred using Argon as inert gas.

- **Process:** Arc Welding.
- **Operation:** Automated
- **Quality Control:**
    - ✓ Periodic and systematic maintenance of the machine is a key factor for quality
    - ✓ Sensors are to be calibrated and measurement tools should reliable
    - ✓ Personal should be trained, qualified and experienced
    - ✓ Welding process should be done indoor.

Figure 46 Linear welding of inner tank [3]

Arc Welding Technology as MIG-MAG welding, or GMAW by U.S. standards, is a semi-automatic welding process. Metal fusion is achieved by the heat energy released by an electrical arc that bursts into a protective atmosphere between a fuse electrode wire and the parts to be assembled continuous wire welding in a protected atmosphere is often referred to as M.I.G. (Metal Inert Gas) and M.A.G. (Metal Active Gas) or, generically, as G.M.A.W. (Gas Metal Arc Welding) Also T.I.G welding (Tungsten Inert Welding).

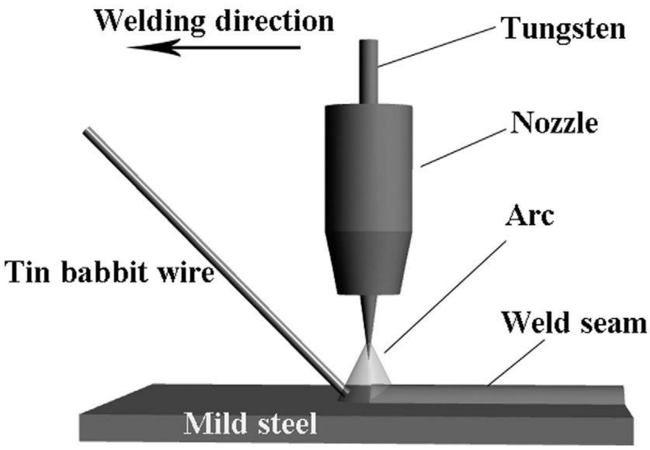


Figure 47 Schematic diagram of arc welding [5]

MIG process uses a solid bare wire to create the arc between the work piece and the filler material. The wire is fed (**usually automatically or semi-automatically**) through a welding gun from a spool or reel. A shielding gas protects the weld from contamination from the environment (oxygen). The gas flows through the welding gun/nozzle to the arc.

The MIG process has a high deposition rate (i.e., the rate at which the electrode melts and gets deposited on the work piece) and can save time and labour costs. However, because the process uses a shielding gas, it is very susceptible to drafts or wind which might blow the shielding gas away from the arc; Thus, **it is not very well suited for welding outside**.

MIG welding is useful because you can use it to weld **many different types of metals**: carbon steel, stainless steel, aluminium, magnesium, copper, nickel, silicon bronze and other alloys.

Here are some **advantages** to MIG welding:

- The ability to join a wide range of metals at different thicknesses
- All-position welding capability
- A good weld bead
- A minimum of weld splatter
- Easy to learn

Here are some **disadvantages** of MIG welding:

- MIG welding can only be used on metals of thin and medium thicknesses
- The use of an inert gas makes this type of welding less portable since it requires external source of shielding gas
- Produces a somewhat sloppy and less controlled weld compared to TIG.

Quality control & Treatment of Linear Welding Cylinder

Remove the extra quantity of welding in the linear line in the cylinder. Visual control of the welding quality, as shown in Figure 48.

- ✓ Appropriate tools and machinery (Grinder and safety tools) should be available for quality control
- ✓ Personal should be qualified for the kind of operation


Figure 48 Linear welding treatment [3]

Dished Heads

It is recommended to outsource manufacturing dished heads. Since it is more feasible in case of mass production.

Dished heads manufacturing

In order to form the two ends of the tank (dished heads), circular **cuttings** are made from sheets using cutting machine, Figure 49.

- **Process:** Cutting
- **Material:** Steel
- **Thickness:** 2.5 - 3 mm
- **Operation:** Automated or Semi-automated.

Figure 49 Circular cutting for tank end covers [4]

Then these circular sheets are formed to the required shape of tank rounded end covers by use of **piston machine**, Figure 50. Also, the edges or the hub and tank are machined to ensure complete matching between tank body and the two ends.


Figure 50 Rounding of inner tank end covers by used of piston

Pipe Connection

Pipe connection is made of steel with threaded ends with a thickness of **4 mm** (outsourced from local market) as shown in Figure 51. These pipe connections are used to connect accessories to the storage tank. Location of pipe connections is determined according to each manufacturer specification.

- **Quality Control:**

✓ Needed qualities of diches and pipes are necessary for good planning
✓ Cleaning of these two pieces is a key factor for quality

Figure 51 Circular cutting for tank end covers

Step 7: Welding Pipe Connections to Dished Heads

Robotic welding of the pipe connections (4 mm thickness) to dished heads. One head will contain 3 pipe connections and electric back-up heater flange in the centre of the dished head. While the other dished head is welded with only one pipe connection at the centre of the dished head, as shown in Figure 52.

Figure 52 Robotic arc welding of pipe connections to dished heads [3]

Quality Control:

- ✓ Periodic and systematic maintenance of the machine is a key factor for quality,
- ✓ Qualification of personal and training on the machine is a key factor for quality,
- ✓ Cleaning of dishes and pipes is a key factor for quality

Figure 53 shows the final shape of pipe connections welded to the dished ends of the inner storage tank.

Location of pipe connections is determined according to each manufacturer specification.

Figure 53 Welded pipe connections [3]

Step 8: Dished Heads Welding to Cylinder

This step become to assemble the inner tank of the storage tank. The assembly is done by welding the two dished heads to the rolled steel sheet. The welding process start by cleaning the surface then followed by tack welding, Figure 54. Finally, circular welding of the two dished heads to the cylinder.

Figure 54 Tack welding and surface cleaning of the circular surface [3]

Quality Control:

- ✓ Cleaning of the components is a key factor for quality
- ✓ Qualification on how to fix the components is a relevant point for quality (based on the welding type and alignment)
- ✓ Cleaning tools and surface of the components is a key factor for quality
- ✓ Qualification of personal and training on the process is a key factor for quality

Step 9: Circular Welding: Dished head with Pipe / Cylinder

Circular welding of the two dished heads is done using automated MIG welding machine. The welding process **MUST** be done indoor, Figure 55. The MIG welding process is using inert gas (Argon).

Figure 55 Circular welding using Automatic MIG welding machine [3]

Quality Control:

- ✓ Tuning and regulation of the machine
- ✓ Periodic and systematic maintenance of the machine is a key factor for quality
- ✓ Quality of inert gas used in welding and needed inputs (accessories)
- ✓ Qualification of personal and training on the machine is a key factor for quality

Reinforcement welding (Optional)

It is done manually by using MIG welding to ensure continuity of the circular welding, as illustrated in Figure 56.

Quality Control of reinforcement welding:

- ✓ Cleaning tools and surface of the components is a key factor for quality,
- ✓ **Verification and visual control** of the product in the end is a relevant factor, (looking for spots that are not welded)
- ✓ Qualification of personal and training on the process is a key factor for quality.

Figure 56 Reinforcement welding [3]

Quality control of the circular welding of the two dished heads to rolled steel sheets is visually testes by expert technician, Figure 57.

- ✓ Verification and visual control of the product in the end is a relevant factor for quality of the inner tank
- ✓ Non conformities should be identified and corrective action should be implemented during the process. (disassemble welding joint, cleaning surface then re-welding the circular)

Figure 57 Qualtiy control of circular welding [3]

The basic conditions of welding quality to achieve products of such high quality includes the following:

- No cracks or holes found in the bead.
- The bead has uniform waves, width and height.
- The finished product satisfies the design dimensions and has almost no distortion.
- The welding meets the required strength

Figure 58 Difference between good and bad welding upper and lower sides [I-car.com/welding]

Step 10: Pressure Testing Inner Tank

Pressure testing is necessary to check the quality and the conformity of the tank. It is needed, to ensure that there are no:

- Cracks
- Pinholes
- Water leakage
- Other discontinuities in the welds

Quality control:

- Cleaning tools and hands of the components is a key factor for quality,
- Qualification of personal and training on testing process is a key factor for quality,
- Verification and visual control of the product in the end is a relevant factor, could be leakage of water in case of using compressed water or leakage of air in case of using compressed air as well as reduction of pressure inside storage tank

Testing process:

1. Set the storage tank
2. Seal the storage tank except the inlet
3. Pump the compressed water/air (14 Bars) by the opening inlet in to the tank
4. Wait 3 min, then inspect the tank and the pressure on the manometer
5. Make the corrective repairs if a leak is detected and the pressure dropped

*Pressure test could be done using compressed air and bath of water (**Ensure Safety**).

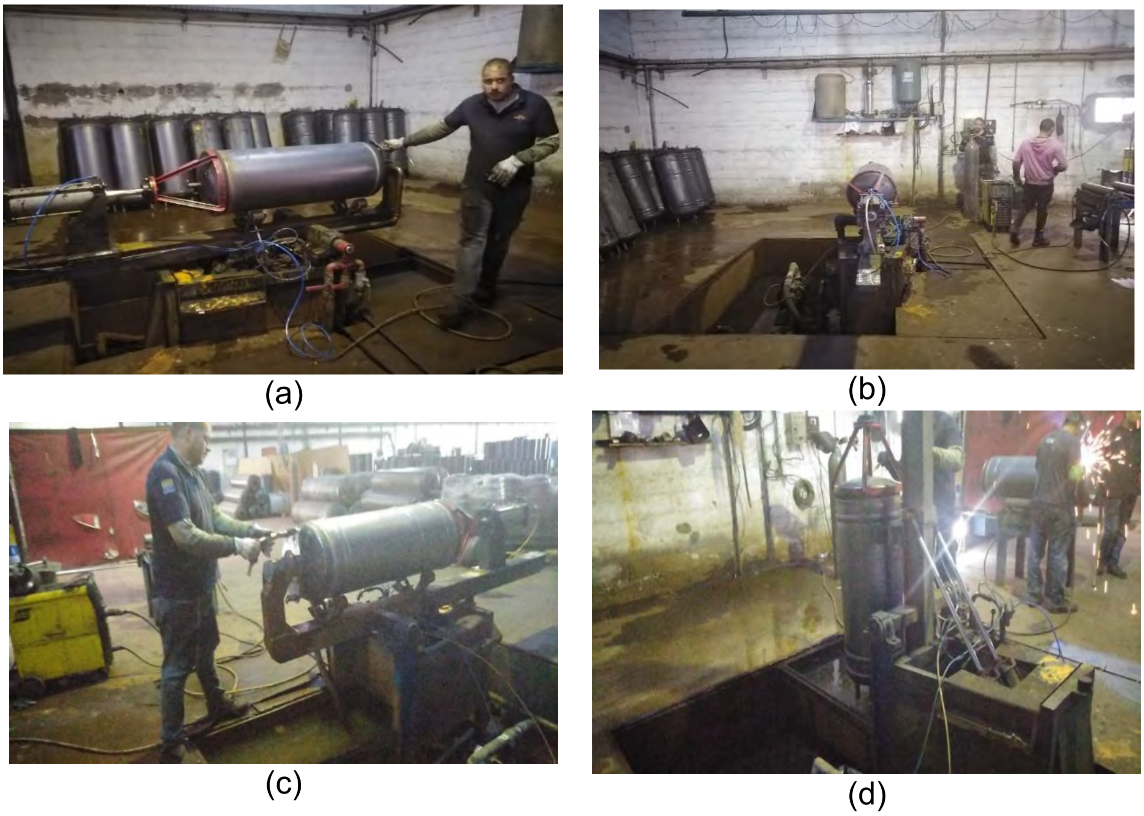


Figure 59 Pressure test steps for the inner tank (a) tank fixation, (b) tank filling with water, (c) installation of pressure gauge, (d) empty tank of water [3]

Figure 60 Water bath for leakage test using compressed air

Step 11: Internal Surface Treatment

The blasting is a treatment process whereby an abrasive medium is propelled against a surface at **high pressure** using blasting nozzles **powered by compressed air**. This procedure strips the surface clean of dirt, debris, surface coatings and rust, without damaging the underlying material. The process is widely used in industry for a range of applications:

- Surface preparation prior to coating, painting or bonding
- Removing rust, scale or existing coatings
- Removing burrs or edge profiling on machined components
- Finishing of precision parts
- Removing mold flash from plastic components
- Glass etching or frosting

Process of sand blasting is done for two pieces (two tanks) per cycle. Figure 62 shows the two tanks preparation and loading to be blasted.

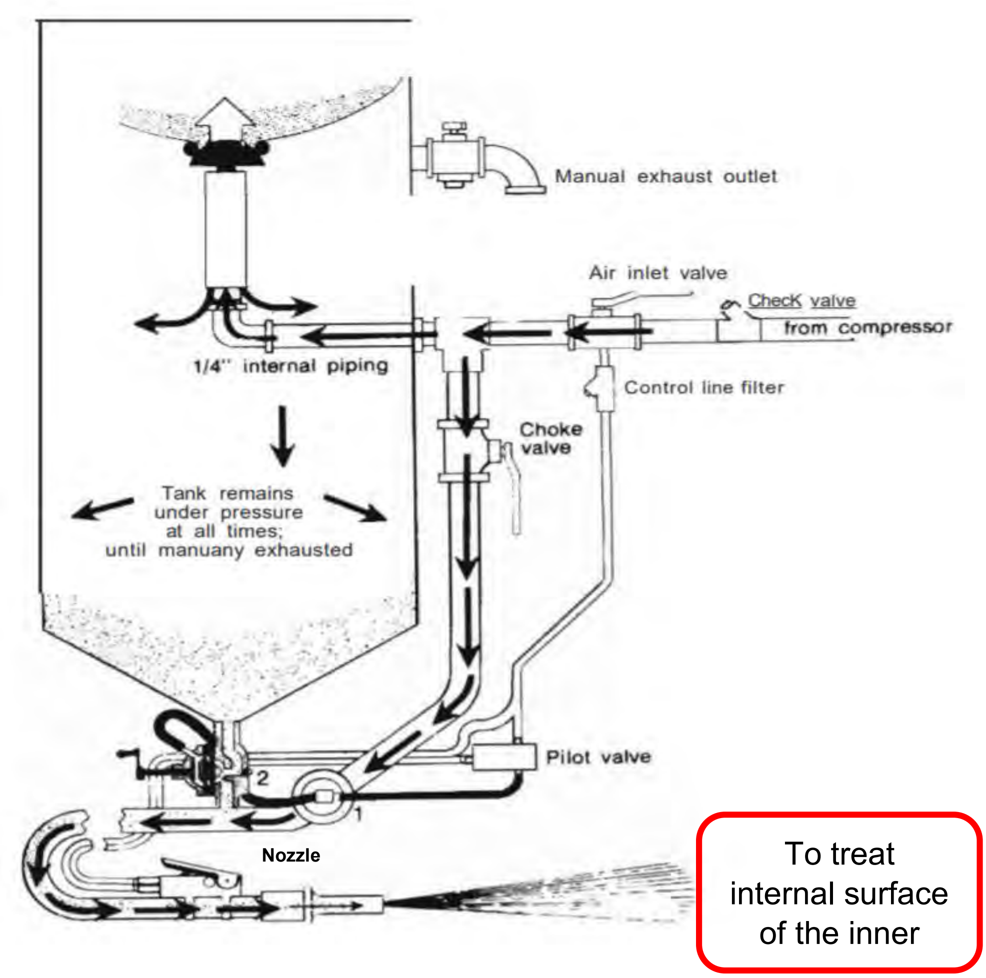


Figure 61 Schematic diagram of portable sand blasting machine [6]

Figure 62 Inner tank sand blasting process (preparation and loading) [3]

Reason of having surface treatment by Blasting:

- ✓ Blasting is considered the best method of surface treatment or preparation.
- ✓ It provides an excellent preparation for coating application.
- ✓ Blasting the steel creates a good profile, essentially cleaning and roughening the surface.
- ✓ **Creating a sharp, angular profile** allows for better coating adhesion and anchoring.
- ✓ This helps **prevent delamination** of the coating from the substrate.
- ✓ This also removes any corrosion and contaminants, such as oil, grease and salts, that may be present on the internal steel. Again, creating a better surface upon which to spray any coatings. Any corrosion damage to the steel will now be evident.

Quality Control:

- Visual control of the blasting quality (using a lamp to check the inner surface of the tank)
- Pipes cleaning from corrosion
- Cleaning of the welding if needed
- Verification and visual control of the product in the end is a relevant factor (No oil, dust, rust or any contamination on the inner surface)
- Qualification of personal and training on the process is a key factor for quality.

Figure 63 Visual inspection after blasting process [3]

Step 12: Inner Tank Coating

In this step the internal surface of the inner tank of the SWH storage tank is going to be coated. The internal coating material must be suitable to the working conditions of the SWH system. The right selection of the coating will ensure long lifetime of the SWH system.

Regarding the conditions in Egypt, using enamel coating over the internal steel sheets will ensure stable operation and long lifetime of the storage tank without any corrosion. However, periodical maintenance of the SWH is mandatory to ensure stable operation.

Reasons to have internal coating:

- Enamel coating is a material made by fusing powdered glass to inner surface of metal tank by firing between **850 °C to 870 °C**. Molecular interaction, resulting in a coating that melts, flows, and then harden to a smooth, durable enamel coating on metal surface.
- After enameling process, coating and steel can't be separated from each other's.
- Enamel coating provides superior longevity to hot water tank
- **In certain areas stainless steel tanks tend to fail more rapidly than glass lined tanks due to chlorides in the water.**
- Enamel coating is flexible and easy to fill internal surface. Moreover, it can cover different sizes of tanks (from 50 to 3000 liters)
- Decrease SWH system maintenance cost during operation.

A. Enamel coating preparation:

- Three types of enamel coating technologies (Flooding, Powder and Spray),
- Enamel coating is a wet process. It is a mixture of base material (Ready to Use - RTU) and Water. The mixing process preparation could take 4 to 6 hours, Figure 64. One tank for the enamel base material, one tank of water and one tank for the mixture RTU material.
- Enamel coating composition is determined from supplier according to the coated surface specification

Figure 64 enamel coating preparation mixing unit [3]

B. Inner tank preparation:

- Tank Uploading. Main flange at one of the end covers is facing down, Figure 65
- Only one connection is open at top for recycling extra injected enamel coating,
- Dryer with hot air injection from the bottom.
- Temperature of injected air is between **120°C and 140° C**, Figure 66
- There is potential for hot air to be recovered from the furnace (furnace used in the firing process of enamel coating).

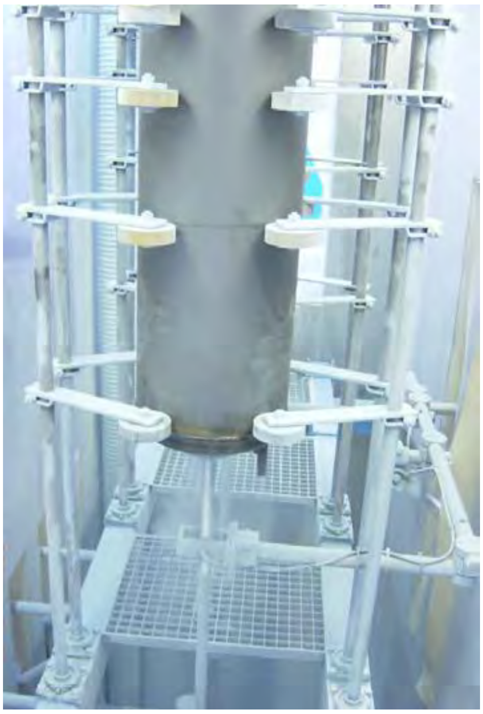
Figure 65 Uploading tanks [3]

Figure 66 Tanks drying tunnel process [3]

C. Enamel coating injection:

Injection process of internal enamel coating is done on 2 positions, Figure 67. First position is done at 60º inclination angle to the horizontal plane taking place for 45 seconds. Followed by the second position done at 105º to the horizontal plane taking place for 25 seconds. It is crucial to highlight that the enamel coating process is so sensitive to ambient air temperature and humidity. Acceptable ambient air temperature and humidity is determined according operating conditions.

Figure 67 Enamel coating injection process (Flooding) [7]



(a)

(b)

Figure 68 Enamel coating by (a) powder and (b) spray[6]

D. **Enamel coating firing process:**

Firing process is done inside furnace by using natural gas as fuel. The furnace is divided into 3 heat transfer areas, Figure 69. The areas are defined as below:

Area 1: Entrance area, where cold tanks are heated by final coated tanks before these tanks exist from the furnace.

Area 2: Tanks to be heated up between **850 °C to 870 °C (hot tanks)**. The heating is done by use of radiant tubes for heating with hot exhausted gases flow inside.

Area 3: Exchange area, where hot coated tanks are cooled down. This heat is transferred to warm tanks.

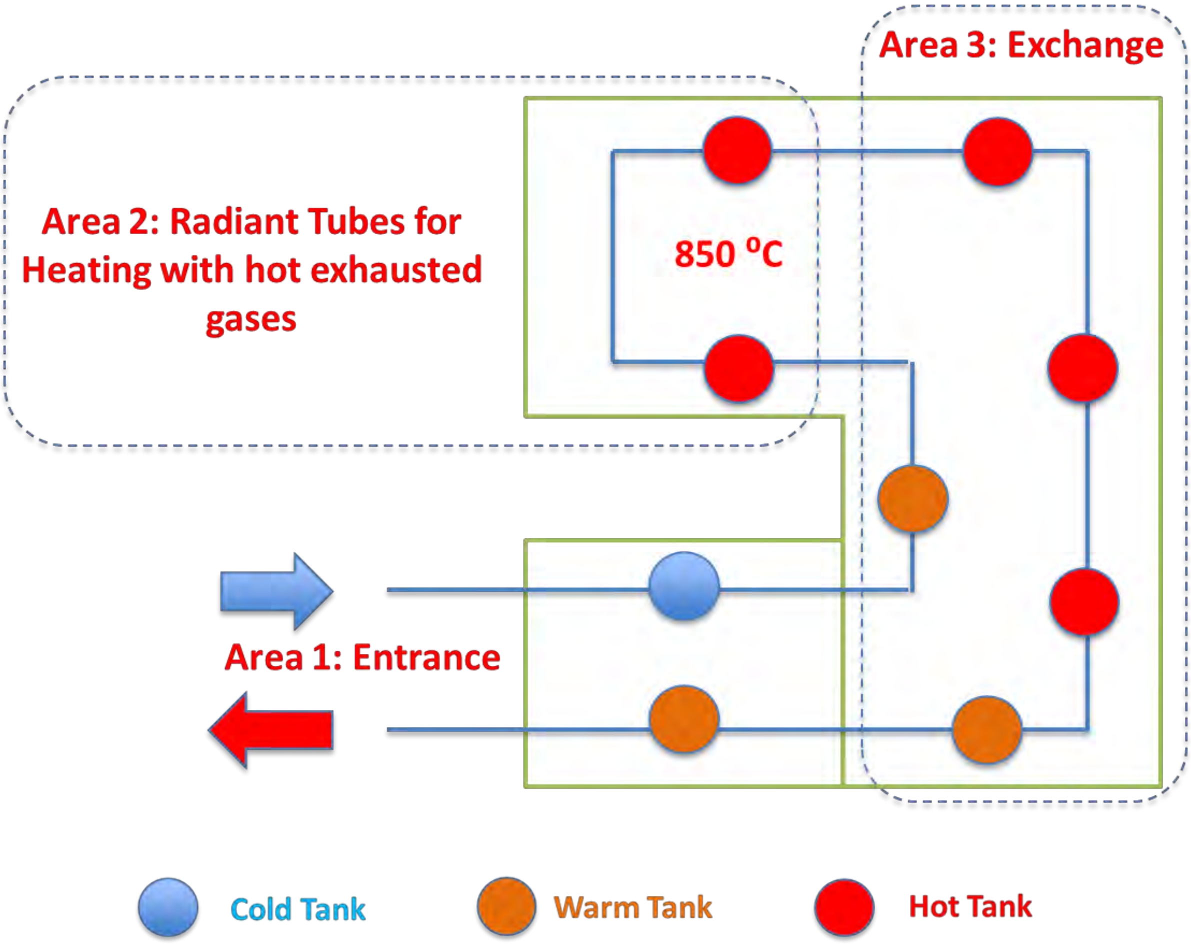


Figure 69 Enamel coating firing process of tanks

Enamel coating furnace tends to work at full capacity. Potential waste heat recovery from furnace could be used to supply hot air between **120°C and 140° C** to the previous step in tank preparation which is tank drying tunnel. Figure 70, shows the different steps of the enamel coating furnace.

(a) (b)

(c) (d)

Figure 70 Enamel coating furnace (a) & (b) Furnace Entrance, (c) Furnace flame sight glass, (d) Exit of enamel coated tanks [3]

Then final end products (internal enamel coated tanks) are kept to cool down naturally as shown in Figure 71.

Figure 71 Enamel coated tanks cooling process [3]

Quality Control before and during coating process:

- Welding process, cleaning tools and inner surface treatment of tanks is a key factor for quality,
- Verification and visual control of the inner tank is a relevant factor for quality (coating is covering all inner surface, weight of injected coating, furnace temperature, ambient operating conditions)
- Qualification of personal and training on the process is a key factor for quality
- Controlled mix of enamel, drying, firing conditions are key factors for quality

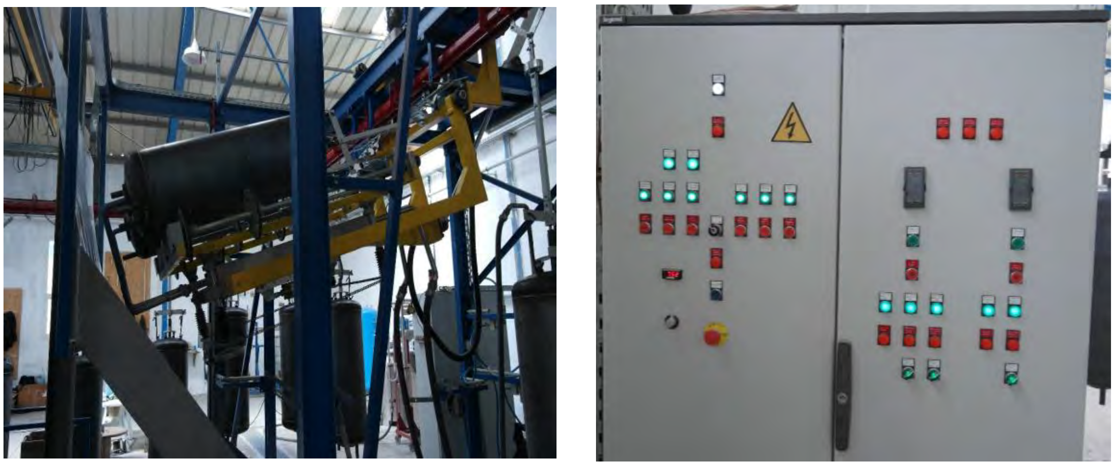


Figure 72 Automated enamel coating process [3]

E. Testing enamel coated tanks:

Test of dielectric intensity (mA) to check if the coating is **homogeneous and covering all the tank**. It gives an idea on the quality of the coating and information on the guarantee duration the manufacturer can offer, Figure 73.

The ASTM D149 [8] provides a decent basis for choosing or developing an appropriate test design. But there are important criteria of a dielectric strength test which are not prescribed clearly by the standard, including voltage ramp rate and electrode size and condition

Test of the coating thickness could be done also by using of ultrasonic thickness detector. Thickness of enamel coating should be within range of **150 µm and 500 µm**.

(a) (b)

Figure 73 Enamel coating thickness testing (a) dielectric intensity and (b) ultrasonic thickness detector

Quality Control after coating process:

At the oven exit and after unloading the tanks, the quality control technician will follow the following steps:

- Check with a **micrometer** (calibrated) if the enamel thickness is between **150 µm and 500 µm** in each point in the inner tank.
- Check with **a torch** if the entire inner surface of the tank is glazed
- It is necessary to check the lines of linear, circular **welding's** and internal side of welding of connection pipes if they are well enameled or not.
  - ✓ **If yes**, send the tanks to product finishing area and then to storage area.
  - ✓ **If no**, you have to rework them or eventually send them **to the blast machine**.
- **Destructive test:** A tank should be cut (longitudinal cross section) after each 2000 tanks production to make a complete test on all the inner surface.

Figure 74 Visual inspection of internal enamel coating [3]

3.4.2 Assembling Process

Assemble process is done after having inner tanks manufactured with internal enamel coating. The assembly with outer tank, insulation and accessories.

Step 13: Outer Tank

Preparation of the outer tank is made of **galvanized steel with thickness of 0.5 -0.7 mm (painted steel sheet)**. This process is done manually as shown in Figure 75. The size of the outer tank diameter should allow free space between outer tank and inner tank. This free space should be at least 50 mm that will be filled with thermal insulation.

Figure 75 Preparation of the outer tank [3]

Quality Control:

- Verification and visual control of the components in the start is a relevant factor (surface finishing of the sheet, avoid unpainted areas, existence of any cracks, well fixation of the separators)
- Qualification of personal and training on the process is a key factor for quality

Afterwards, fixing the inner tank with the outer tank as shown in series of Figure 76. Starting by rolling the inner tank with stretch then rolling outer tank over the inner tank using separators to ensure free space between inner and outer tanks. This free space is kept for thermal insulation.

(a)

(b)

Figure 76 Fixing process of outer tank including (a) packaging with stretch inner tank and (b) fixing separators between inner and outer tanks [3]

Quality Control:

- Good tools, raw material and appropriate machineries are relevant factors for quality
- Qualification of personal and training on the process of finishing are a key factor for quality,
- It is crucial to ensure that inner tank and outer tank are concentric. This could be determined by measuring the distance of between the inner and outer tanks is constant in all directions. Measurement is done using Vernier calliper.

Step 14: Plastic Cowls

Fixing the plastic cowls manually, as shown in

Figure 77. It is crucial the labour is equipped with safety gloves. The labour must ensure that the plastic cowls are well sealed and the inner and outer tanks are concentric. In the need of mass production these plastic cowls are mainly outsourced, according to manufacturer specifications.

Figure 77 Plastic cowl fixing [3]

Step 15: Thermal Insulation

The reasons to fill the gap between inner and outer tanks with insulation material are:

- To maintain tank temperature during the absence of solar resources
- Generate significant energy savings by reducing heating losses
- Improve operation and system efficiency
- Insulation should be appropriate and high quality
- The manufacturer should check that the insulation is well done when the tank is assembled.

The thermal insulation suggested to be used in SWH storage tank is foam **(Polyurethane)**, Figure 78.

- **Polyurethane** (expanded foam insulation) is ideally suited to insulating storage tanks.
- Polyurethane insulation adheres to the surface of the tank, **fills any cracks or seams** and creates a weather-tight insulating layer between the external covering and the storage tank
- The **physical properties** of polyurethane are considerable. Polyurethane performs well for hardness, tensile strength, compression strength, impact resistance, abrasion resistance and tear strength
- Polyurethanes are produced by reacting an isocyanate with a polyol in the presence of a catalyst or by activation with ultraviolet light and the proportions are 1 kg of polyol for every 1,2 kg of isocyanate.
- A **thickness of 50 mm** of polyurethane is considered adequate
- The density of the foam have to be between **40 and 50 kg/m^3**
- Thermal insulation injection is done through layers. It could be done through 3 injection layers to ensure no air bubbles are trapped inside.

Figure 78 Foam insulation injection machine [3]

Quality Control:

- Good tools, raw material and appropriate machineries are relevant factors for quality
- Systematic, periodic and preventive maintenance for machineries are relevant quality factors
- Qualification of personal and training on the process of finishing are a key factor for quality.

Testing of Thermal Insulation Quality:

1. Fill the tank with hot water at fixed temperature
2. Install the tank outside at ambient temperature
3. Check tank temperature after 24 hours.
4. **Maximum heat losses accepted is 4°C/ 24h**
5. **Alternative test is by using thermal camera for scanning the outer tanks surface.**
6. Knocking test to ensure well distribution of thermal insulation (Well curing time)

Step 16: Tank Accessories

Final step before packaging is fixing tank accessories. Tank accessories is consisting of: seal joint, barrel (Stainless Steel) and Mg rod. Below are the steps for fixing tank accessories.

Assembly process start at storage tank flange, by fixing seal joint, Figure 79, then adding barrel that is made of stainless steel, Figure 80. Followed by inserting Mg rod inside the tank through stainless steel barrel, Figure 81. The technician will assemble the whole set of accessories using screws, Figure 82.

Figure 79 Seal joint fixing [3]

Figure 80 Barrel (Stainless Steel) fixing [3]

Figure 81 Mg rod fixing [3]

Figure 82 Fixing barrel at end [3]

Quality Control:

- Qualification of personal and training on the process of finishing are a key factor for quality
- Good tools, raw material and appropriate accessories are relevant factors for quality.

Step 17: SWH Storage Tank Packaging

Sealing all inlets and outlets of the storage tank to avoid any dust or substance from entry. Using plastic stretch for packaging, Figure 83. Moreover, it is important to have a good traceability system with solid data management system, Figure 84. Traceability system will facilitate tracking raw material and maintenance.

Figure 83 Packaging of SWH storage tank

Figure 84 Traceability of each SWH storage tank

Quality Control:

- Traceability, data indication, good management of storage are key factor for quality
- Good tools, storage area conditions and appropriate accessories are relevant factors for quality

3.4.3 Manufacturing of Heat Exchanger

In case of manufacturing SWH storage tank equipped with internal heat exchanger. The heat exchanger is assembled inside inner tank before welding the dished heads, step 8.

A) Heat exchanger tube coiling

Heat exchanger is made through a long tube in the shape of coil. This process can be done using mandrel bending machine.

- **Process:** Bending
- **Material:** Copper or Steel
- **Sizes:** Tubes (3/4 – 1 1/4 inches)
- **Operation:** Automated.

Then a steel rods is **welded (brazing welding)** to heat exchanger to make it rigid, as shown in Figure 85 [9].

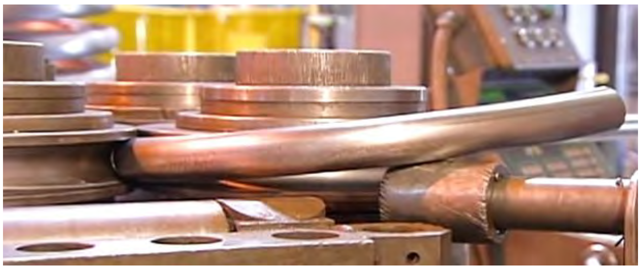


Figure 85 Heat exchanger coiling

B) Inner coating of heat exchanger tube

The coiled heat exchanger is coated from inside with ceramic coating to ensure complete protection for inner surface against corrosion as shown in Figure 86. This coating takes about six minutes to fully coat the inner surface and drain the remaining liquid.

- **Process:** Enamel coating
- **Material:** Enamel
- **Operation:** Semi-automated.

It takes about 15 minutes inside furnace to cure the applied coating, **similar to inner tank enamel coating process**. Afterwards it is settled down on a base in order to be ready to be fitted inside the inner tank.

Figure 86 Heat exchanger tube inner coating

C) Outer coating of heat exchanger tubes

The coiled heat exchanger is coated from outside as shown in Figure 87 [10]. The coating is done using spray process.

- **Process:** Coating
- **Operation:** Semi-automated, Manual.

Figure 87 Heat exchanger tubes outer coating [10]

3.4.4 Double Jacketed Heat Exchanger

The manufacturing of double jacketed storage tank, Figure 88, is the same as manufacturing of embedded coil storage tank (with heat exchanger) except for the following:

- Manufacturing of heat exchanger tubes step does not exist as there is no embedded coil inside the inner tank.
- Inner tank consists of double walled rolled steel sheets with free space in between. The hot heat transfer medium coming from solar collector will flow inside the free space. While the application water is located inside the inner tank.
- The two rolled steel sheets (double walled sheets) are welded together by use of circular arc welding, Figure 89.
- Different ports sizing and location compared to the embedded coil storage tank. The location and size should be determined according to manufacturer design and specification.

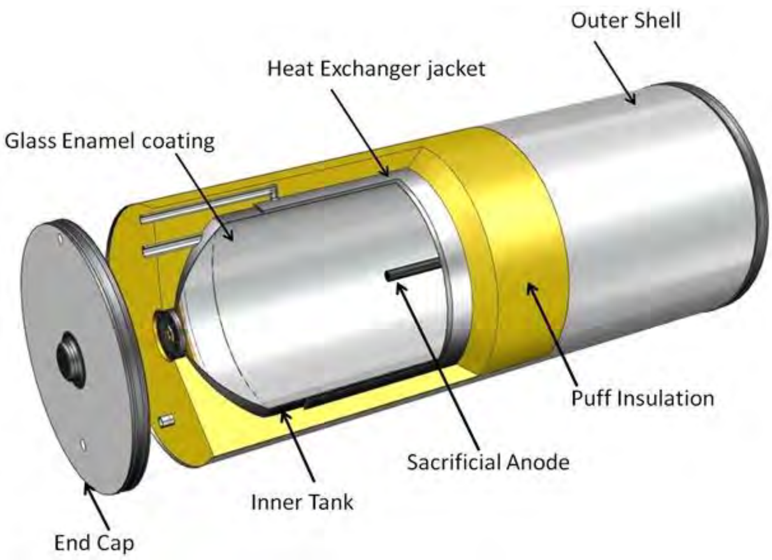


Figure 88 Sample of double jacket storage tank

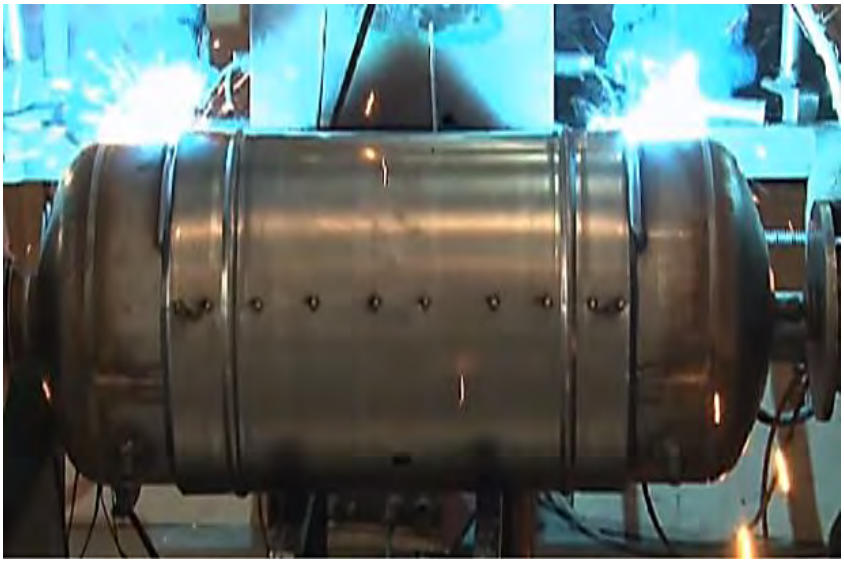


Figure 89 Circular arc welding of double walled rolled sheets

Conclusion

The quality of tank manufacturing depends on:

Steel quality

- Low carbon steel and especially for coating

Welding quality

- No cracks or holes found in the bead.
- The bead has uniform waves, width and height.
- The finished product satisfies the design dimensions and has almost no distortion.
- The welding meets the required strength

Surface treatment quality

- Visually and with blasting process

Coating quality

- Visually and the enamel thickness have to be between 150 μm and 500 μm.

Insulation quality

- A thickness of 50 mm of polyurethane is considered adequate
- Polyurethane density has to be between 40 and 50 g/m3
- A maximum heat loss of 4°C/24h

Control quality of all steps

Table 7 Summary of SWH storage tank manufacturing requirements [1]

Item	Details
Input Material	• Inner tank: Low-carbon steel sheets, • Outer tank: galvanized steel sheets, • Thermal insulation between inner and outer tanks, • Inner tank: internal coating, • Outer tank: external coating, Copper tubes/Stainless steel tubes (Heat exchanger and back-up element).
Specification	• Low-carbon steel sheets (inner tank): 2.5 - 3 cm thickness • Galvanized steel sheets (outer tank): 0.5 – 0.7 cm thickness • Thermal insulation: PU Foam density (50 – 70) kg/m^3, 40 – 50 mm minimum thickness, • Internal coating: enamel coating with minimum thickness of 150 - 500 µm • External coating: Electrostatic coating, outdoor, Average weight: 28 kg
Key Manufacturing Process (es)	• Surface cleaning (sandblasting or degreasing using chemicals) • Rolling (inner and outer tank) • Arc welding • Enamel Coating (Inner tank) • Thermal insulation curing time (in case of using foam) Bending (Heat exchanger and back-up element)
Quality Control Inspection	• Well stress distribution due to good rolling process • Leakage test at pressure of 10 bar gauge using air or water • Thermal leakage test to ensure well distribution of thermal insulation (Well curing time) • Knocking test to ensure well distribution of thermal insulation (Well curing time) • No cracks at welding areas of the inner steel tank Enamel coating thickness inspection
Note	• For exporting, it is crucial to use recommended enamel coating, • Avoid using thermal insulation sheets with aluminium foil as the foil separates releasing toxic gases. Affecting the performance and distribution of the thermal insulation • Avoid using stainless steel sheets as material for the inner tank, Avoid using galvanized steel sheets as material for inner tank, • Ensure the minimum enamel coating of 150 µm.

3.5 Manufacturing of Flat plate collector

Flat-plate collectors are the most widely used kind of collectors in the world for domestic water-heating systems and solar space heating/cooling. The first accurate model of flat plate solar collectors was developed by Hottel and Whillier in the 1950's. Flat plate collector consists mainly of absorber, thermal insulation and glass cover, Figure 90.

The absorber: is usually a sheet of high thermal conductivity metal such as copper or aluminum, with tubes either integrated or attached. Its surface is coated to maximize radiant energy absorption and to minimize radiant emission.

The thermal insulation: reduces heat loss from the back or the sides of the collector.

The cover sheets, called glazing: allow sunlight to pass through the absorber but also insulate the space above the absorber preventing cool air to flow into this space.

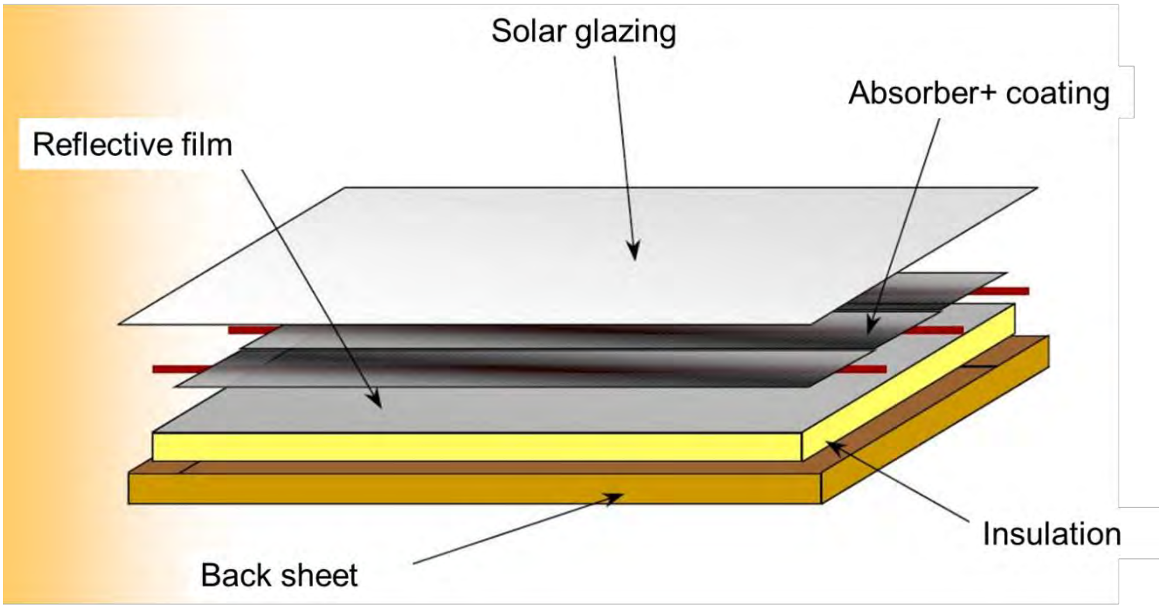
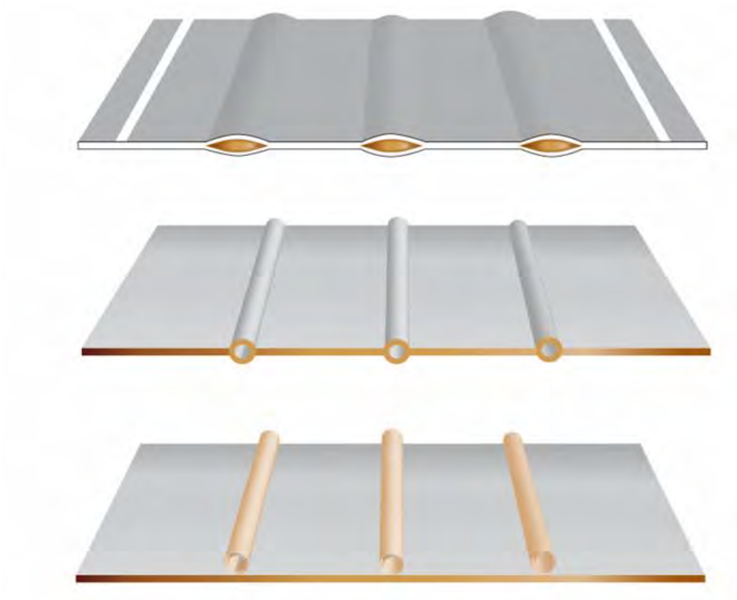


Figure 90 Flat plate collector main components [3]

There is no standard for manufacturing absorber sheet. As the technology is always developing, Figure 91, is showing different configuration of absorber plate. These configurations are recommended to be used. The recommended material for absorber sheet and pipes is copper or Aluminium.



- Aluminium absorber sheet and copper plate sheet (with grooves in between)
- Copper pipe between two copper plates
- Copper pipe welded to a sheet of copper or aluminium

Figure 91 Different absorber configurations [3]

Absorber grid form, normally two type of grid forms exists, Figure 92. **First type is Scale form**, this type is considered **a low-pressure losses type** since the heating fluid go through short path of absorber tubes. Second type is called **Serpentine form**, this type is considered **a high-pressure losses type** since the heating fluid go through long path of absorber tubes.

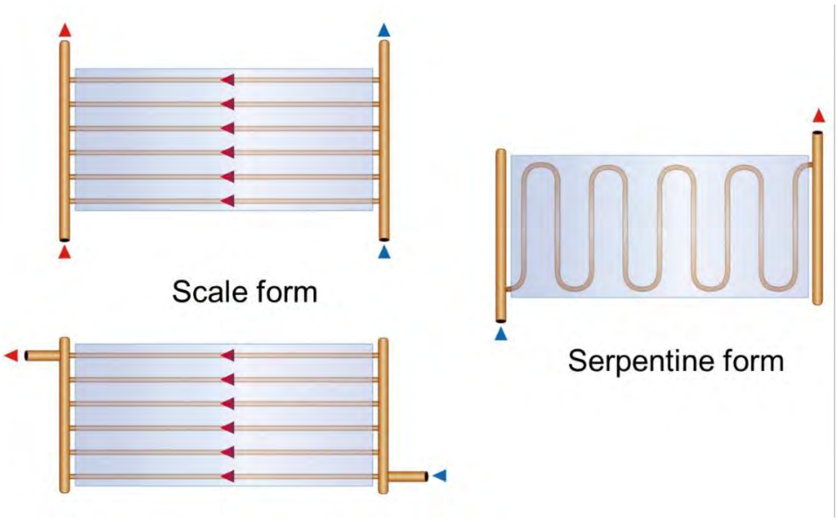


Figure 92 Absorber grid form types [3]

Table 8 is introducing comparison between both types of absorber grid forms. Selection of the absorber grid form is determined according to the application.

Table 8 Comparison between scale form and serpentine form per absorber

For same mass flow rate per absorber	Scale form has lower heating transfer medium temperature rise than Serpentine form
	Scale form has **lower pressure drop** than Serpentine form

Regarding implementation of SWH system that may consist of several collectors. **Two possible collectors (absorbers) connections types: Parallel and series connections**, Figure 93. These two of connections could be done using scale or serpentine forms of absorber.

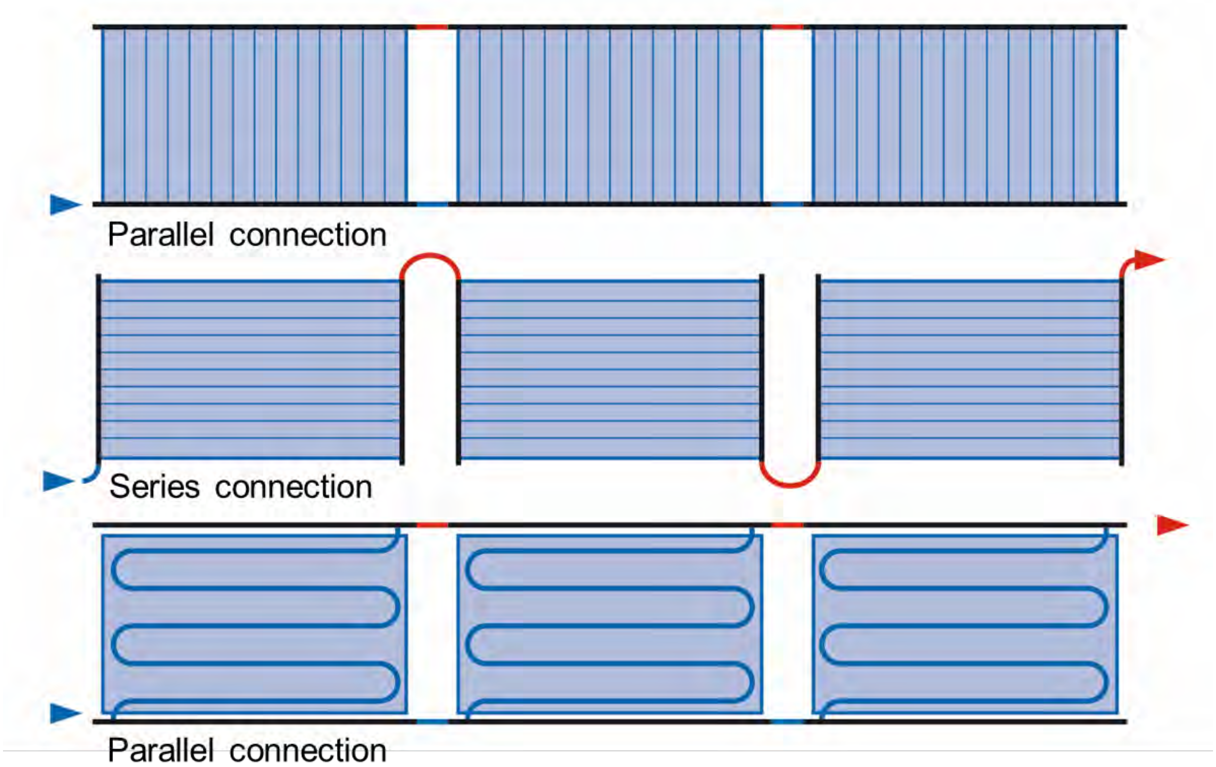


Figure 93 Absorber types of connections [3]

Table 9 is introducing comparison between possible combination of absorber grid forms and type of connections. Selection of the absorber grid form is determined according to the application.

Table 9 Comparison between different absorber grid forms and types of connections

Absorber Grid	Type of Connection	Temperature Rise	Flow Rate	Pressure Drop
Serpentine	**Parallel**	Medium	Medium	Medium
Serpentine	**Series**	High	Low	High
Scale	**Parallel**	Low	High	Low
Scale	**Series**	Medium	Medium	Medium

Another important material is the absorber coating. This coating is used to improve the absorptivity of the absorber. **Main advantages of absorber coating are:**

- High absorption + low emissions coefficient
- Non-corrosive, stable in the long term
- Simple coating process
- Optimization of use of land and raw material costs

Absorber coating is one of the most important elements of the collector; it converts solar radiation into heat. It is characterized by two parameters:

- the **solar absorption factor α** (or absorptivity): the ratio of the light radiation absorbed by the incident light radiation
- the infrared **emission factor ε** (or emissivity): the ratio between the energy radiated in the infrared when the absorber is hot and the ratio that a black body radiates at the same temperature.

In solar heating applications, the best ratio of solar absorption factor to infrared emission factor is sought, this factor is called **selectivity**.

Optimum choice is based on selectivity and maximum temperature which coating can withstand. This is illustrated in Table 10. Optimum choice should have highest selectivity factor and high maximum temperature. **It is concluded that TINOX (selective coating) and black Chrome both are suitable choice, with respect to maximum working temperature of the collector**, Figure 94.

Table 10 Available absorber coating material

Material	Absorptivity α	Emissivity ε	Selectivity α / ε	Max. Temperature
Black nickel	0.88 - 0.98	0.03 - 0.25	3.5 - 32	300 ° C
Graphitic movies	0.876 - 0.92	0.025 - 0.061	14.4 - 36.8	250 ° C
Black copper	0.97 - 0.98	0.02	48.5 - 49	250 ° C
Black chrome	0.95 - 0.97	0.09 - 0.30	3.2 - 10.8	350 – 425 ° C
TINOX	0.92 – 0.95	0.02 – 0.04	23 – 47.5	100 – 120 ° C

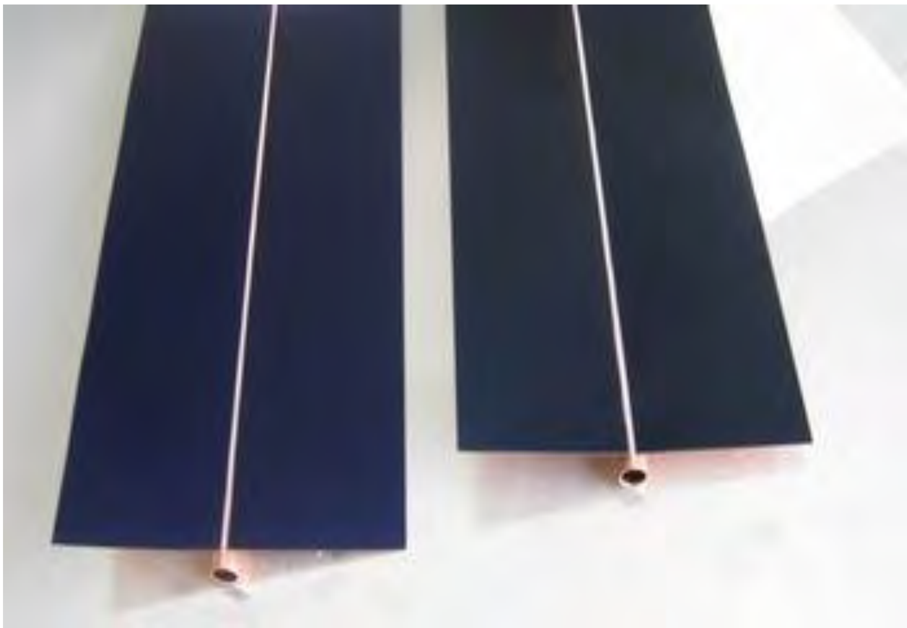


Figure 94 Absorber coating (left) Tinox and (right) black Chrome

Flow chart for flat plate collector manufacturing processes, Figure 95, **consists of 12 main steps**. Later in this section, illustration of each step description as well as determination of quality control needed in each part of manufacturing.

Table 11 Required inputs of flat plate collector [1]

		Main Components			
		Mounting structure	**Storage tank**	**Flat plate Collector**	**Evacuated Tube collector**
Metals	Steel sheets	✓	✓		
	Stainless Steel Sheets		✓		
	Aluminium			✓	
	Copper		✓	✓	✓
Non -Metals	Insulation		✓	✓	
	Glass			✓	✓
Coatings	Internal Coating		✓		
	External Coating		✓		
	Absorber Coating			✓	✓

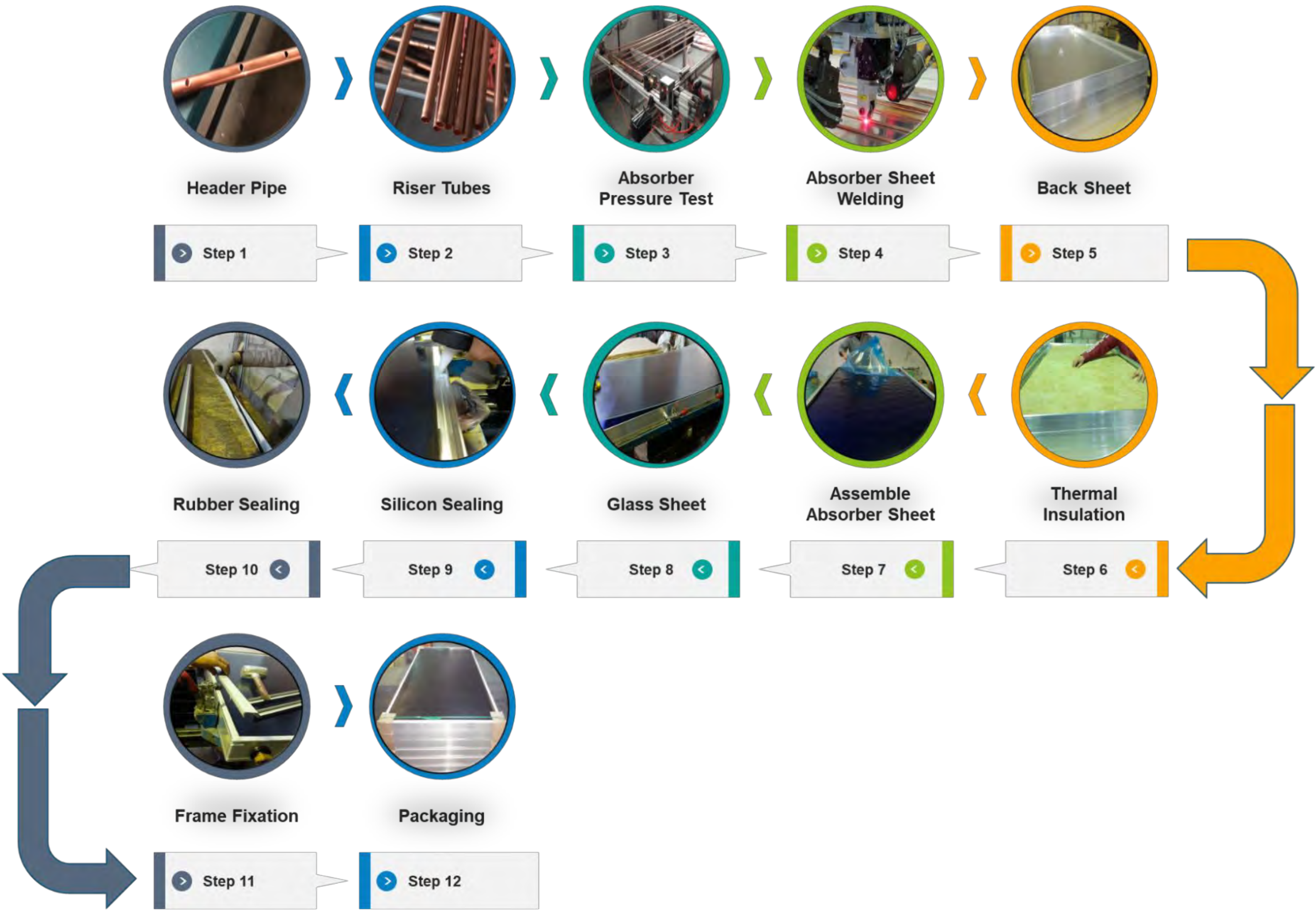


Figure 95 Flow chart of flat plate collector manufacturing process

Definition of raw material

Thermal insulation role and characteristics are:

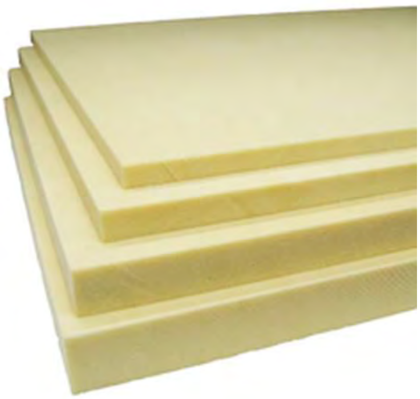
- Reduce the heat losses from the back and sides of the collector
- It should be resistant to the maximum stagnation temperature of the collector usually about **200°C** when selectively coated absorbers are used. At these high temperatures the insulation should not shrink, melt, or give off vapors ("outgas"), which could condense on the collector cover and reduce its solar transmittance.
- Resistant to water to avoid water penetration
- High thermal conductivity (0.03 - 0.04 W/m.K)
- High durability to the presence of moisture

The average thickness of the thermal insulation is **between 30 and 40 mm**. While the main materials used for collectors are:

- Rock wool
- Glass wool
- Polyurethane foams.

Rock wool 3 – 4 cm

Glass wool 3 – 4 cm



Polyurethane 3 - 4 cm

Figure 96 Thermal insulation materials

Aluminium frame:

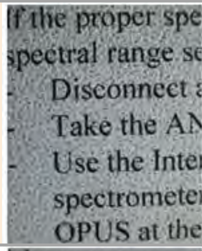
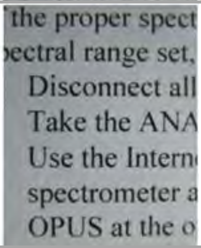
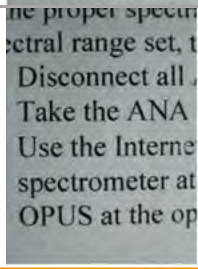
- The frame provides the structural stiffness in a collector (in some collectors' polyurethane sheets contributes to the stiffness).
- It holds together the transparent cover, the absorber and the insulation.
- The most common designs employ aluminium extruded profiles (anodized or painted for corrosion protection) to form the sides
- The frame should be designed to **permit differential thermal expansion** between components.
- Fastenings should be carefully selected to prevent corrosion between dissimilar materials.
- **Thermal bridges between the hot absorber and the casing should be minimized.**
- Attention should be given to the frame design ensuring it will not deform under service conditions (long sides of the frame must be connected by appropriate "links").
- **Water-tightness** between the frame and the transparent cover (glass sheet) is very important for the collector reliability.
- Because of the risks of water penetration in solar collectors with aging, it may be considered preferable that the casing is designed with **drain holes** and with adequate **ventilation**. At the same time provision should be taken to prevent insects from entering the collector.

Glass Sheet, an efficient glazing, it must have the following properties:

- Reflect the light radiation to the minimum regardless of its inclination
- Absorb light radiation to a minimum
- Have good thermal insulation by keeping the infrared radiation to the maximum,
- Resist with time the effects of the environment (rain, hail, solar radiation, ...) and large temperature variations.
- "**Low iron", tempered glass** is used in many collectors for mechanical strength, for safety and for higher collector efficiency.
- It has higher transmittance to the solar energy (higher efficiency) as well as **higher mechanical strength** (lower failure rates) than the common glass.
- In addition, tempered glass breaks into a large number of relatively harmless bits of glass and so it is safer to use
- Thickness is in the range of 3 mm to 4 mm

Several types of glass are available in the local market. The selectivity of the right material is based on the Transmission factor, Table 12.

Table 12 Glass sheet materials with transmission factor

Glass Type	Transmission Factor	Sample of Vision Behind Glass
Normal Glass	85 % - 88 %	
Ultra-clear Glass	91.7 %	
Low-iron Glass	92.7 %	
Low-iron Glass with Reflecting Coating	Up to 95 %	

Connecting pipework (Accessories) should have the following characteristics:

- To resist at high temperature and the corresponding pressures
- The commonly used material is **copper**
- Avoid the use of **galvanized steel**
- Plastic or multilayer tubes are prohibited for temperature higher than **70 °C**
- Thermal insulation is mandatory to minimize heat losses
- The insulation of the external pipes has to resist to UV light
- Recommended water velocity ranges from 0.5 to 2 m/s.

In the following section, illustration of the manufacturing steps of flat plate collector. These steps are to be as best practice guide.

The manufacturing steps include manufacturing absorber sheet. While the national roadmap developed by UNIDO 2019, recommend for newly starting business to assemble the flat plate collector and later manufacturing process of the absorber sheet could be included.

Step 1: Header pipe

Header tube punching and flanging

After cutting copper header tubes to the required tube length, holes of riser pipes are made along header tubes using punching machine, Figure 97,

- **Process:** Punching
- **Material:** Copper
- **Sizes:** Tubes diameter (3/4 - 1 inches)
  Holes (3/8 - 5/8 inches)
- **Thickness:** Tubes (0.7 mm)
- **Operation:** Automated or Semi-Automated.

Figure 97 Punched holes along header tube length [4]

Header tube connection joint preparing

After punching, connection joints are **welded** at the two ends of the header tube, Figure 98, to be connected later to tank/system water pipes. Copper joint connection is outsourced at the need of mass production.

- **Process:** Welding (Brazing)
- **Material:** Copper
- **Sizes:** compatible with header pipe diameter
- **Operation:** Automated, Semi-Automated or Manual.

Figure 98 Header tube fitted with connection joints [4]

Brazing Welding is a joining process wherein metals are bonded Together using a filler metal with a melting (liquidus) temperature greater than 450 °C, but lower than the melting temperature of the base metal. Filler metals are generally alloys of silver (Ag), aluminium (Al), gold (Au), copper (Cu), cobalt (Co) or nickel (Ni).

Step 2: Riser tubes

Riser Tube End Shrinking

Shrinking of the riser tubes ends is done in order to be fitted in the header tube holes, Figure 99,

- **Process:** Shrinking
- **Material:** Copper
- **Sizes:** Tubes diameter (3/8 – 5/8 inches)
- **Thickness:** Tubes (0.4 mm)
- **Operation:** Automated

Figure 99 Shrinking of the ends of riser tubes [4]

Riser Tubes welding in header tube

After shrinking riser tubes ends, it is fitted into the holes that was made before in header tube. Then riser tubes are **welded** to header tube, Figure 100,

- **Process:** Welding (Brazing)
- **Material:** Welding using silver
- **Operation:** Automated, Semi-Automated or Manual

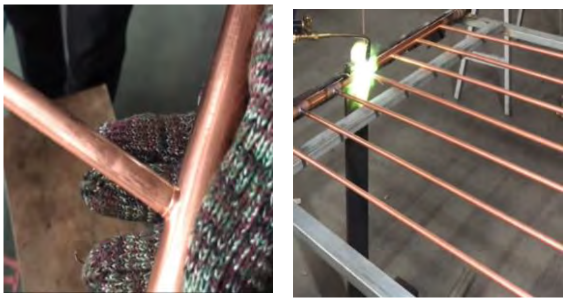


Figure 100 Welding riser tubes with header tube [4]

Step 3: Leakage testing of absorber tubes

A **leakage test** is performed on the assembly of absorber tubes, riser and header tubes, to assure complete welding between riser and header tubes and fix any leakage points that exist. Figure 101 shows an example set up for leakage testing. Below are the pressure testing steps for absorber:

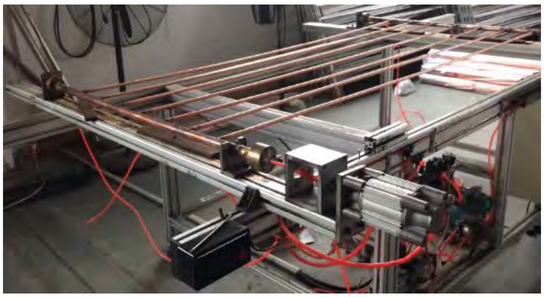


Figure 101 Sample setup of leakage testing of absorber tubes [4]

- Set the absorber
- Seal the absorber except one inlet and the diagonal outlet pipe
- Pump compressed water/air compressor (10 -12 bars) by the opening inlet in to the absorber
- Read the pressure by manometer at the outlet pipe
- Make the corrective repairs if a leak is detected and the pressure is not the same at the outlet pipe

Step 4: Absorber sheet

Roughen treatment on riser tubes

After leakage testing of riser and header tubes, the surface of riser tubes is **roughen treated** in order to prepare it to the next step. Figure 102 shows an example of the process,

- **Process:** Roughen Treatment (Automatic grinding machine)
- **Operation:** Automated.

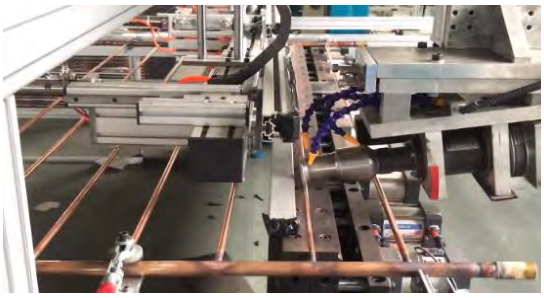


Figure 102 Example setup of the roughen treatment process [4]

Absorber sheet welding

After rough treatment of riser tubes, the absorber sheet is positioned on the treated surface of riser tubes, Figure 103,

- **Process:** Assembly
- **Material:** Copper or Aluminium
- **Coating:** Selective Coated
- **Thickness:** 0.2 - 0.4 mm
- **Operation:** Manual.

Figure 103 Absorber sheet positioning on the treated riser tubes [4]

Then absorber sheet is **welded** to riser tubes using either **ultrasonic welding**, Figure 104, or **laser welding**, Figure 105. This process is **Automated**.

- **Process:** Welding
- **Type:** Ultrasonic or Laser Welding
- **Operation:** Automated.

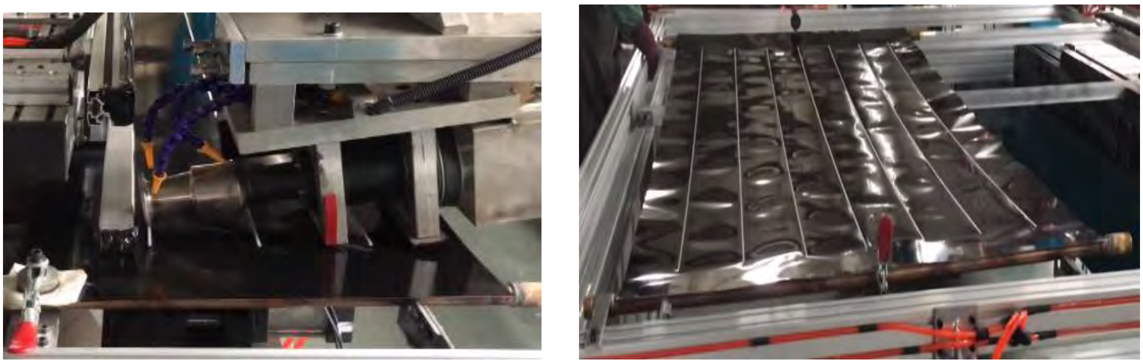


Figure 104 Sample setup and final result of ultrasonic welding process [4]

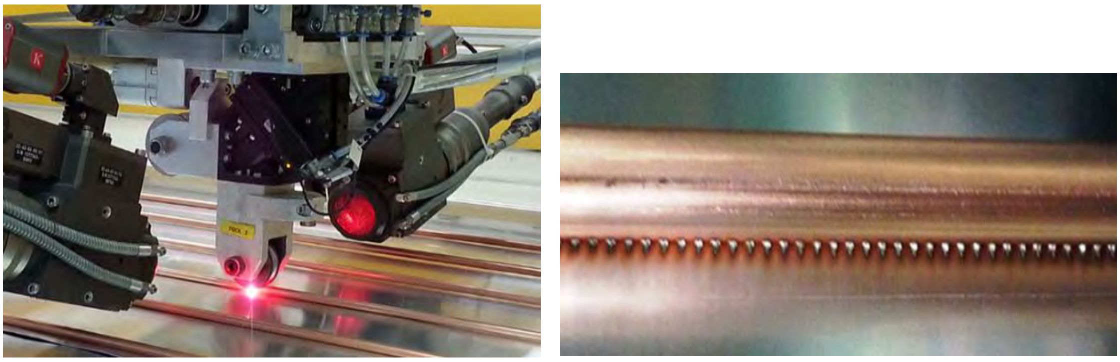


Figure 105 Laser welding of riser tubes and absorber sheet [4]

Step 5: Collector Assembly

Frame, back plate assembly

The collector frame is formed by using sheet **metal bending and forming** equipment. This step is done according to manufacturer's requirements.

This step recommended to be outsourced at the need of mass production. After that, the back sheet of the collector is fitted in the frame. Back sheet material can be either **galvanized steel or Aluminium**. Sheet thickness varies between 0.5 – 1.0 mm, Figure 106.

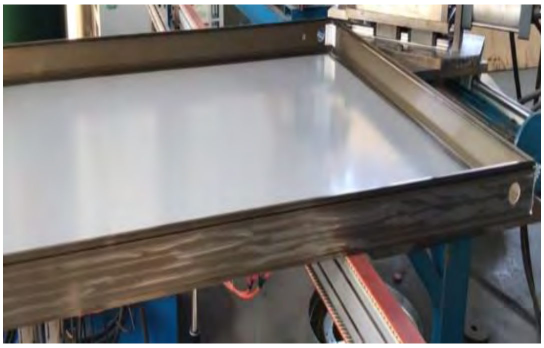


Figure 106 Frame and back plate assembly [4]

- **Process:** Assembly
- **Material:** Steel or Aluminium
- **Coating:** Galvanized (steel), Painted (Aluminium)
- **Holes sizes:** Compatible with header pipe diameter
- **Thickness:** 0.5 – 1.0 mm
- **Operation:** Manual.

Insulation frame assembly

Insulation is placed inside the frame casing, Figure 107.

- **Process:** Assembly
- **Material:** Mineral or Polyurethane
- **Thickness:** Mineral (40 - 50 mm back), Polyurethane (30 - 35 mm)
- **Operation:** Manual.

Figure 107 Insulation placement inside the frame casing [3]

Absorber plate frame assembly

After insulation, the absorber assembly is installed above insulation as shown in Figure 108.

- **Process:** Assembly
- **Material:** Absorber sheet
- **Operation:** Manual.

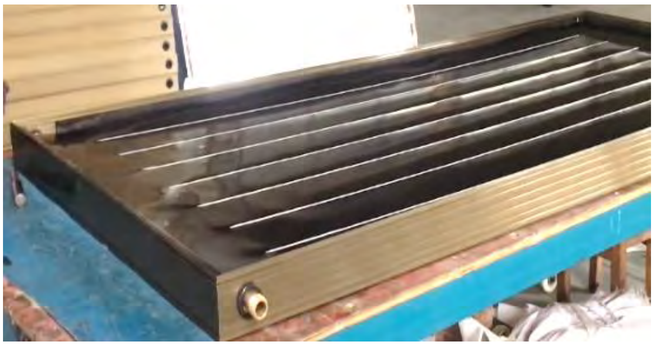


Figure 108 Absorber plate and frame assembly

Quality Control of Flat Plate Collector Manufacturing

- Qualified technician
- Back sheet in Aluminium
- Frame according to manufacturer design and aesthetic
- Scratch system of the insulation in the back sheet, Figure 109. It is used to fix the thermal insulation at its position during handling.
- Insulation according to manufacturer design and selected material
- Absorber with good quality according to manufacturer design and selected material, Figure 110.
- Pipes of absorber should be adapted to water quality

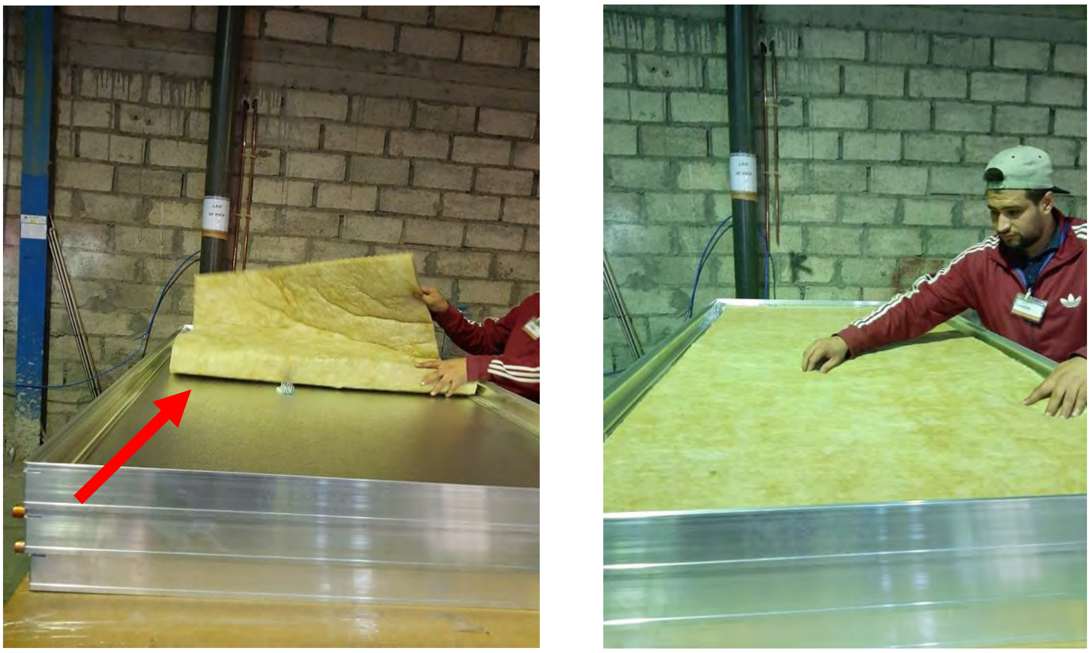


Figure 109 Scratch system in assembly of flat plate collector [3]

Figure 110 Absorber assembly [3]

Tempered glass cover and sealing rubber assembly

After sealing assembly around inlet and outlet pipes. A transparent sheet of low iron tempered glass is used as collector cover, with thickness of 3 - 4 mm. The use of sealant material should also be combined with the proper glass support resulting is the final assembly of flat plate collector, Figure 111.

- **Process:** Assembly
- **Material:** Low iron tempered glass
- **Thickness:** 3 - 4 mm
- **Operation:** Semi-Automated or Manual

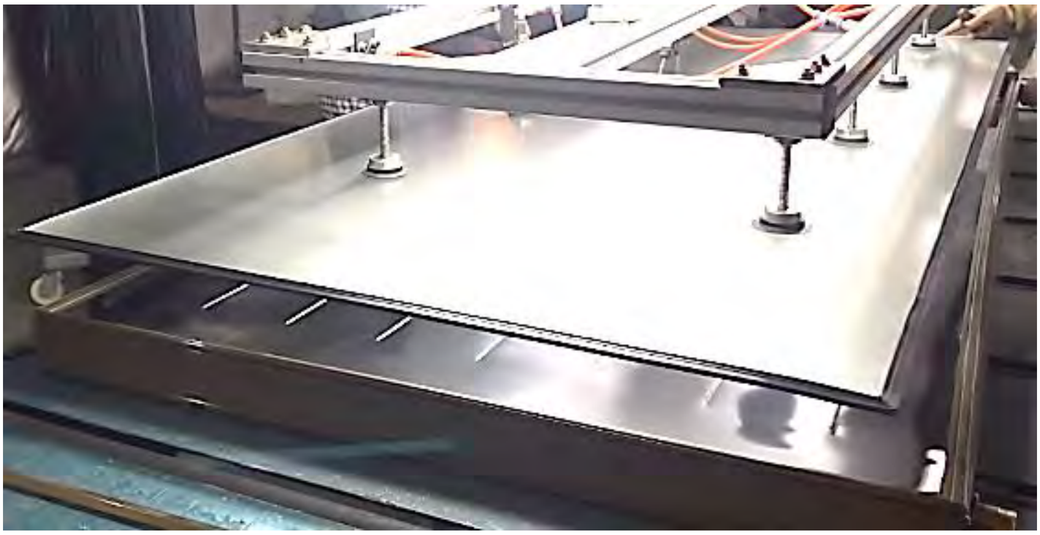
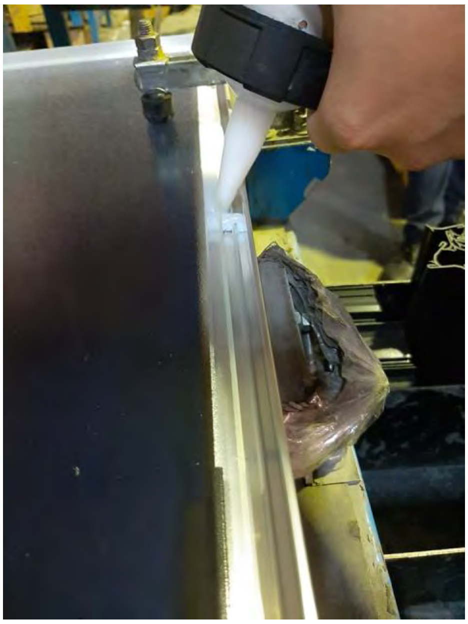


Figure 111 Final assembly of flat plate collector with glass cover [3]

Silicon sealing

Fixation of glass sheet to frame is done using thermal silicon. It is important to use thermal silicon for waterproofing. Thermal silicon must withstand temperature at least 200 ºC.



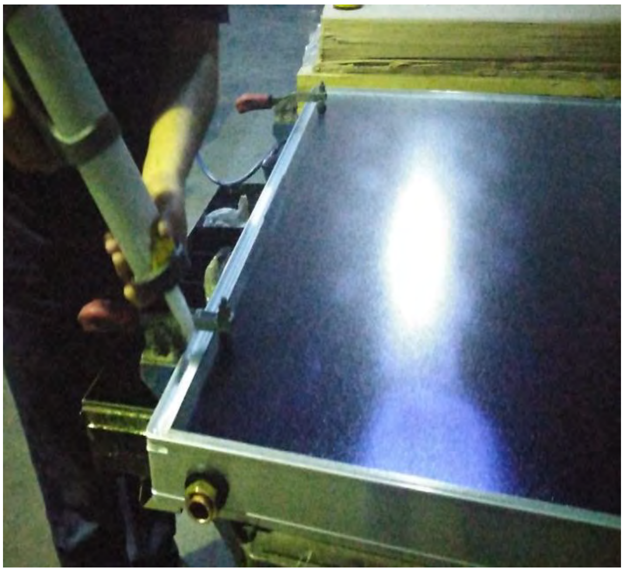


Figure 112 Silicon fixation [3]

Rubber sealing

Fixation of Aluminium frame to frame is done using rubber. It is important to use rubber for waterproofing. Rubber sealing must withstand temperature at least 200 ºC.

Figure 113 Rubber sealing fixation [3]

Frame fixation

After fixation of rubber sealing to the frame. The frame bars are assembled to the collector. Using rubber hammer to avoid destroying glass sheet.

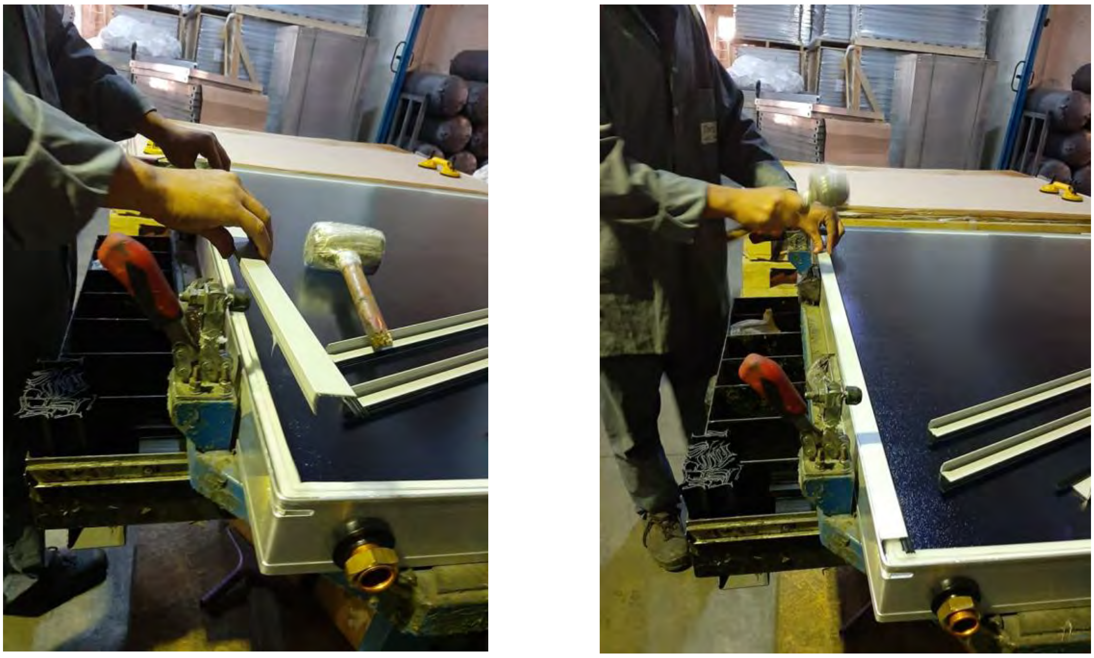


Figure 114 Flat plate collector accessories [3]

Step 6: Packaging of flat plate collector

A final step of assembly process is to close all pipe connections. Moreover, using corner covers to protect the sharp edges of the collector during transportation. The collector is packed with all the parts including the connection pipework.

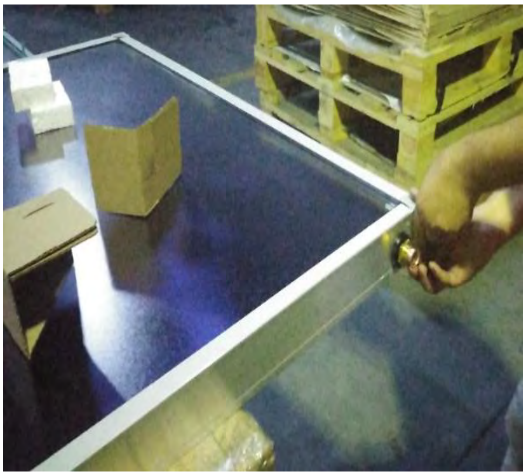


Figure 115 Pipe connections closing [3]

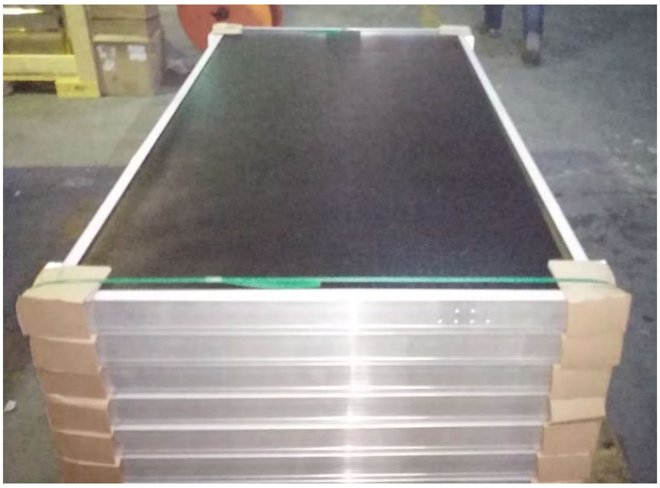


Figure 116 Flat plate collector packaging [3]

Quality Control of Flat Plate Collector Assembly

- Qualified technician
- Glass with good quality
- Treated glass against contamination
- Silicon with good quality
- Silicon should be applied in the needed quantity
- Rubber in good quality
- Rubber adapted to the frame with long time life

Table 13 Summary of flat plate collector manufacturing requirements [1]

Item	Detail
Input Material	• Aluminium sheets (Back sheet), • Absorber, • Thermal insulation, • Glass sheets, • Aluminium bars (Frame), • Gasket, • Glue material, • Fittings.
Specification	• Aluminium sheets: 0.5 – 1.0 mm thickness • Absorber: Fins (Copper of Aluminium) with thickness of 0.1 – 0.2 mm, riser tube (Copper of 3/8 – 5/8 inch), tubes are laser welded with fins, selective coated • Thermal insulation: Foam density (50 – 70) kg/m^3, 40 – 50 mm minimum thickness • Glass Sheets: Low-iron tempered glass with thickness of 3 – 4 mm • Gasket (Anti-leakage): Rubber (E.P.D.M), withstand temperature up to 200 ºC • Glue material: Outdoor, withstand temperature up to 200 ºC • Fittings: Copper, withstand temperature up to 200 ºC • Average weight: 40 kg
Key Manufacturing Process (es)	• Leakage test at pressure of 10 bar gauge by using air or water • Thermal leakage test to ensure well distribution of thermal insulation (Well curing time) • Knocking test to ensure well distribution of thermal insulation (Well curing time) • Copper fittings should withstand 10 bar gauge test • Acquiring Solar Key Mark or SHAMCI label
Quality Control Inspection	• Leakage test at pressure of 10 bar gauge by using air or water • Thermal leakage test to ensure well distribution of thermal insulation (Well curing time) • Knocking test to ensure well distribution of thermal insulation (Well curing time) • Copper fittings should withstand 10 bar gauge test • Acquiring Solar Key Mark or SHAMCI label
Note	• Avoid using traditional glue material, • Ensure good ventilation at the back side of the flat plate collector, • Using ultra-clear glass sheet instead of low-iron will reduce collector efficiency around 5%, • Avoid using steel absorber tube of fins, • To maximize collector efficiency, use of selective coated absorber is better than black matt coated absorber, • Avoid using thermal insulation sheets with aluminium foil since separation of the foil will occur releasing toxic gases affecting the performance and distribution of the thermal insulation.

3.6 General Tips for Assembly Evacuated Tubes with Storage Tank

In case of using SWH system equipped with evacuated tube collector. Egypt has no potential for manufacturing evacuated tubes locally in the short term as concluded from the national roadmap. However, some manufacturers prefer to use evacuated tubes especially with industrial applications. The best practice manual present below general tips for assembly evacuated tubes with SWH storage tank.

Evacuated tube consists of vacuum glass tube. This tube is coated internally with selective absorbing material. For pressurized tubes, another copper pipe (heat pipe condenser) with heat transfer fluid that has low saturation temperature is placed inside the glass tube. Concentrating fins might be used to enhance heat transfer. Then centring tuber stopper to keep all in place. Finally, the heat pipe that entre the storage tank or collector header.

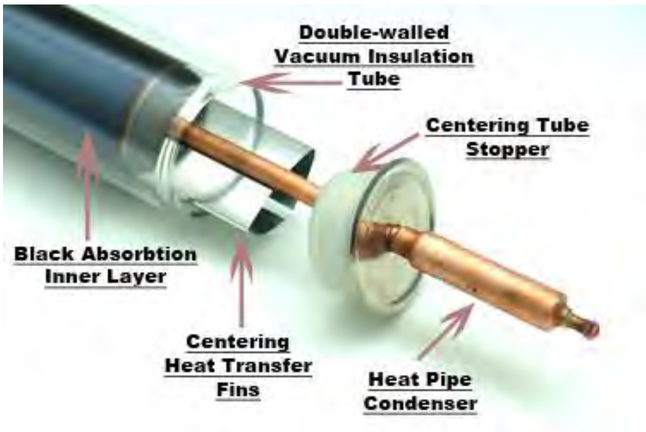


Figure 117 Breakdown of Evacuated tube (Pressurized)

To place evacuated tube inside the storage tank, it is crucial to use seals (dust cover ring). This seal must withstand temperature of 200 ºC and humidity and well cleaning to the outer surface of the tube. Apply mixture of water and soap on the outer surface of the tube. Then insert the seal before inserting the tube into the storage tank. Repeat the same process for all tubes. Ensure that tubes are not loss.

Figure 118 Assembly of evacuated tube with storage tank

Quality Control of Evacuated Tube Assembly

- Qualified technician
- Glass with good quality
- Treated glass against contamination
- Rubber in good quality
- Rubber adapted to the frame with long time life
- Vacuum is kept inside tube
- Heat pipe material is preferred to be copper

3.7 Manufacturing of Mounting Structure

The main parts of the mounting structure for solar water heaters:

1- Back Leg
2- Triangle Support
3- Tank Support
4- Leveling Bar
5- Rear Support Bar
6- Front Support Bar
7- Forefoot
8- Support Base
9- Wedges

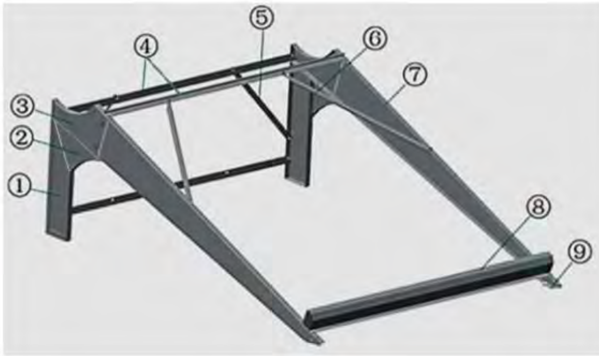


Figure 119 Main parts of the mounting structure

To produce the mounting structure for solar water heating systems, an engineering software like REVIT must be used to design the system to determine the dimensions, angles and slopes of each part in the mounting steel structure. The fabrication of metal structure is done by cutting, bending then drilling based on design specifications.

- **Steel Angles:** 4 cm with 2 - 3 mm thickness
- **Steel bolts:** diameter 10 – 14 mm
- **Coating:** Epoxy, withstand water and humidity
- **Paints:** Outdoor, withstand water and humidity
- **Average weight:** 20 kg
- **Process:** Cutting, drilling holes and painting

Figure 120 Mounting for forced system collector

Quality Control:

- Assembly by using **steel bolts and avoid** using **welding**
- **Importance** of covering **epoxy coating** by **outdoor paints**
- Take into consideration stress distribution of water volume
- No unpainted areas
- Withstand minimum weight of 45 – 50 kg/m^2
- No cracks around the ends and side of steel angles raw material.

Table 14 Required inputs of mounting structure [1]

		Main Components			
		Mounting structure	**Storage tank**	**Flat plate Collector**	**Evacuated Tube collector**
Metals	Steel sheets	✓	✓		
	Stainless Steel Sheets		✓		
	Aluminium			✓	
	Copper		✓	✓	✓
Non -Metals	Insulation		✓	✓	
	Glass			✓	✓
Coatings	Internal Coating		✓		
	External Coating		✓		
	Absorber Coating			✓	✓

Table 15 Summary of mounting structure manufacturing requirements [1]

Item	**Details**
Input Material	Steel angles, steel bolts, epoxy coating, paints
Specification	• Steel Angles: 4 cm with 2-3 mm thickness • Steel bolts: diameter 10 – 14 mm • Epoxy Coating: Outdoor, withstand water and humidity • Paints: Outdoor, withstand water and humidity Average weight: 20 kg
Key Manufacturing Process(s)	• Surface cleaning for steal angles, Metal bending
Quality Control Inspection	• Well stress distribution • Withstand minimum weight of 45 – 50 kg/m^2 • No unpainted areas No cracks around the ends and side of steel angles
Note	• Avoid using welding instead of assembling by steel bolts, Importance of covering epoxy coating by outdoor paints.

Section 4: General Organization for SWH Manufacturing

4.1 Introduction

This section is focusing on the organization of SWH manufacturing facility to optimize manufacturing time. Moreover, to facilitate the handling process of materials during manufacturing processes.

The manufacturing facility space is divided in several production areas according to Table 16.

Table 16 Distribution of manufacturing facility space over SWH components

Manufacturing Facility Space	Sub-Component	Dealing With
Shear area	Inner tank	SWH Storage tank
Welding area	Inner tank	
Blasting area	Inner tank	
Internal coating area	Inner tank + Heat exchanger	
Testing tank area	Inner tank	
Preparation outer tank area	Outer Tank	
Foaming area	Thermal insulation	
Absorber and collector assemble area	--------------	Flat plate collector
Mounting structure area	--------------	SWH Mounting structure
Connecting pipework area	--------------	All components
Raw material area	--------------	All components
Final storage product area	--------------	All components

4.2 Shear Area

Figure 121 Shear area [3]

4.3 Welding and Blasting Area

Figure 122 Welding area (left) and blasting area (right) [3]

4.4 Welding Area

Figure 123 Rolled tanks area and MIG-MAG welding area [3]

4.5 Piping and Steel Angles Area

Figure 124 Mounting area and pipework area [3]

4.6 Thermal Insulation Area

Figure 125 Support Structure area and foam injection area [3]

4.7 Leakage Test Area

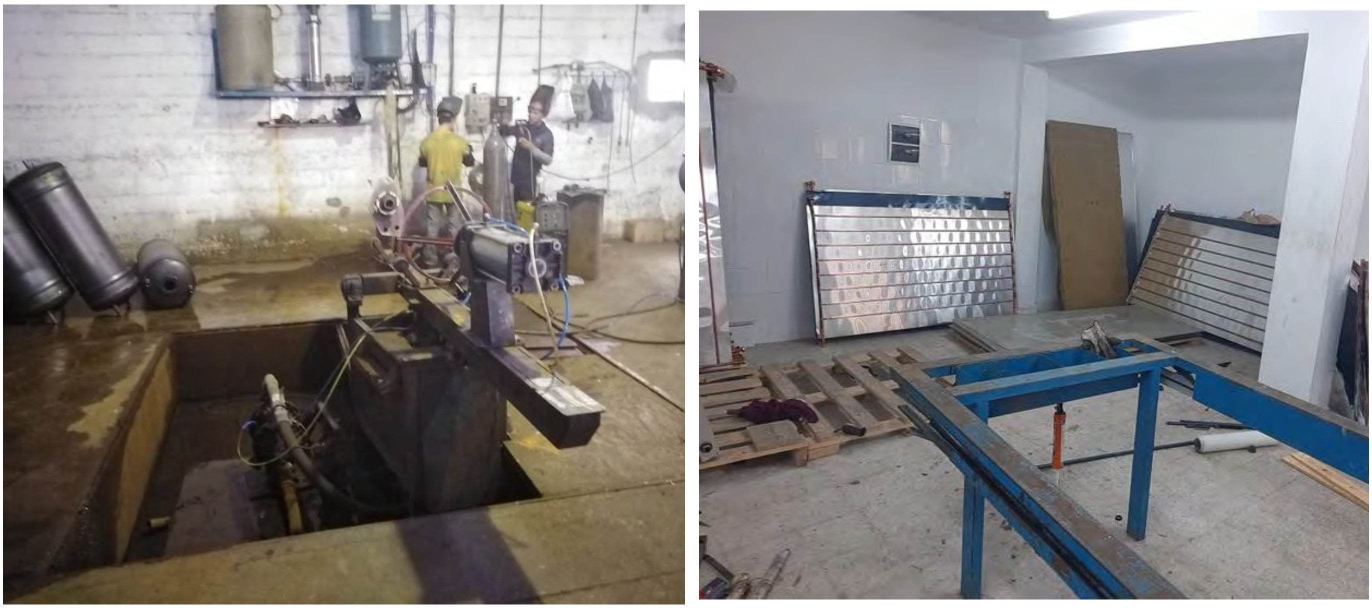


Figure 126 Storage tank testing area and absorber testing area [3]

4.8 Storage Area


Figure 127 Raw material and Final product storage area [3]

4.9 General View of SWH Facility

Figure 128 General view of SWH organization [3]

Conclusion

Collector and SWH manufacturers certification

- Solar Key Mark: European certification
- SHAMCI: Arabian certification

QMS ISO 9001

- Can be adopted by any organization
- focused towards the meeting of customer requirements and enhancing of customer satisfaction

Section 5: In-house checks for R&D and QA

5.1 Introduction

This section is focusing on illustration of the required tests to ensure high quality of locally produced SWH system collectors. It is recommended to carry the following tests in-house within the manufacturing facility;

- Exposure test,
- Exposure + External Shock (only for non-tempered glass),
- Exposure + Internal Shock (**Danger**),
- Mechanical load (positive load).

It is not necessary to repeat all tests in case of developing one item of the SWH components.

5.2 Exposure Test

This test is aimed at ensuring that there is no outgassing inside the collector as well as that absorber has minimum free area to expand and ensure stability of seals at high operating temperature.

Procedure

1) Expose a finished collector in stagnation (By preference in summer)
   Orientation: South
2) Inclination: Maximum at noon (about 30° in Egypt)
3) Close all inlet and outlets connections EXCEPT for one connection at the bottom as shown in Figure 129.
4) Let it there for 30 hot sunny days.
5) Make photos before as reference

Figure 129 Exposure test for flat plate collector [11]

Check 3 times (morning / noon / evening)

- Outgassing on the glass?
- Is the absorber touching the glass?
- Is the absorber touching the frame?
- Colour of the absorber ok?
- Are the gaskets ok (in and outlets)?
- Are all sealing ok?
- Is humidity inside?
- Is dust/sand inside?

If a collector didn't pass this test, that means the collector is accepted however, these problems need to be fixed.

5.3 Exposure + External Shock (only for non-tempered glass)

This test is aiming at ensuring that the glass sheet is tempered. It is crucial to ensure that glass can withstand high operating temperature.

Procedure

1) Same fixation of the collector for the normal exposure test.
2) Expose as required for Exposure.
3) Await at least 10 days of exposure
4) 30 minutes after noon:
   Spray cold water on the glazing for 10 minutes

Check

If the glass is OK, it means the glass is tempered. **If cracks exist that mean the collector failed**.

5.4 Exposure + Internal Shock (Danger!)

This test is aimed at ensuring that the absorber can withstand internal thermal stress as well as the welding within the absorber sheet.

This test is considered a high-risk test since there is a potential for steam formation and high pressure that might yield to leakage if the welding joint failed to withstand the high pressure.

Procedure

1) Expose as required for Exposure test.
2) Await at least 10 days of exposure
3) 30 minutes after noon: Make sure that you have cold available.
4) Connect cold water at the open inlet.
5) Open second connector on top (red), as shown in Figure 130.
6) Flush with cold water for 5 Minutes.

Attention steam!

Check

If the absorber is Ok, it means the glass sheet will not have hot spots.

If hot spots exist on the outer surface of the glass sheet, that means the collector need to be fixed. However, the collector didn't not fail.

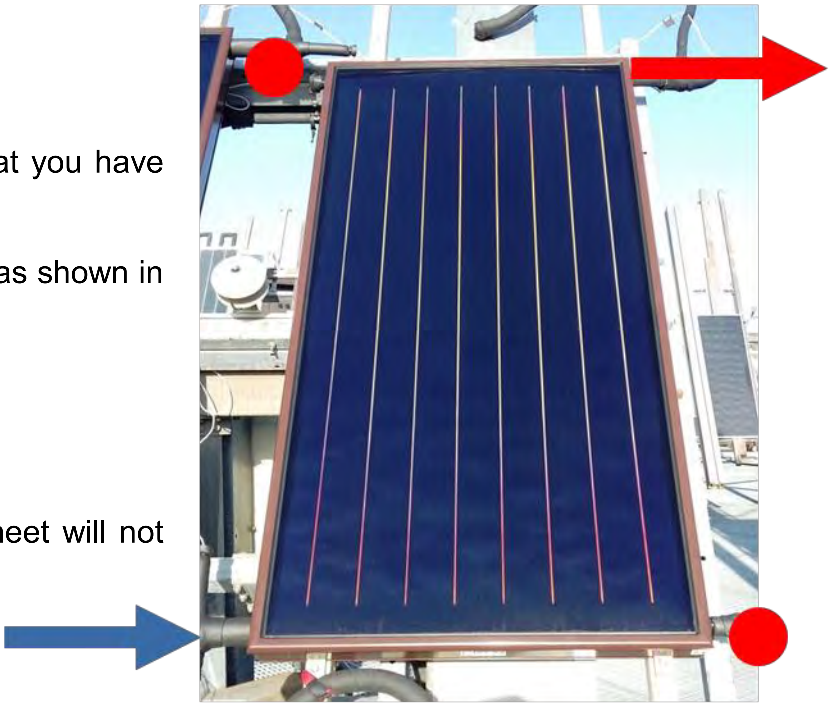


Figure 130 Water flow direction for exposure test (internal shock) [11]

Final inspection – welding problems

5.5 Mechanical load (positive load)

This kind of test is needed to ensure that the collector can withstand wind load and generated stress from high wind speed. This test must be applied for both collector and mounting structure.

Procedure

Apply loads using any kind of soft load similar to sand bags, water bags or water.

The standard load in Europe to be applied is 240 kg/m^2 (approximately 80 km/h wind speed)

Check

Deformation of the casing

Glass crashing

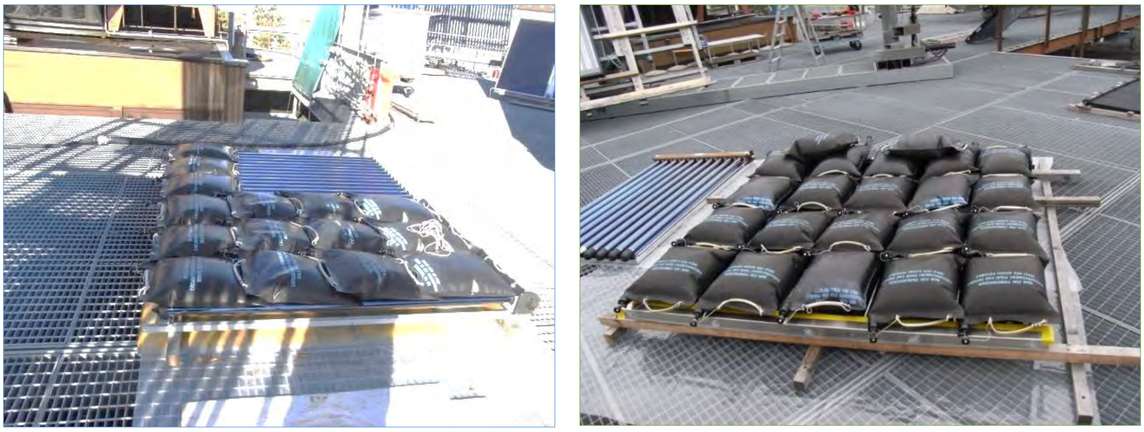


Figure 131 Mechanical load testing [11]

Mounting structure, mechanical load could be applied for mounting structure also.

If the test fail, that mean the collector or the mounting structure failed design of raw material thickness and quality should be checked.

5.6 Final inspection

SWH collector manufacturer could use below list as a check list for R&D and quality assurance department to follow. Such kind of documentation would facilitate development process.

Procedure

Inspect from outside then open the collector carefully

Check

Outgassing on the glass?

Is the absorber touching the glass?

Is the absorber touching the frame?

Welding/contacting ok?

Burnt items? Bad smell?

Oil/Grease on the glazing?

Colour of the absorber is ok?

Are the gaskets ok (in and outlets)?

Any not needed openings / holes?

Are all sealing ok?

Is there humidity inside?

Is there dust/sand inside?

Do you like what you see?

If all positive that mean the collector passed. If not, try to solve the problem and conduct the tests again to ensure the good quality and safety of the SWH system.

5.7 Analysis of Inspection after exposure and shocks for SWH collector

Analysis

Outgassing on the glass?	Source: Insulation / Glues / Gaskets
Is the absorber touching the glass?	Mounting of absorber
Is the absorber touching the frame?	Mounting of absorber
Welding/contacting is ok?	Mounting/Production of absorber
Burnt items? Bad smell?	Check maximum operating temperatures
Oil/Grease on the glazing?	Source: Insulation / Glues / Gaskets
Colour of the absorber is ok?	Can be outgassing! Bad absorber
Are the gaskets ok (in and outlets)?	Temperature / Mounting of absorber
Any openings / holes?	Gaskets / seals / deformation
Are all sealing ok?	Temperature / Mounting of absorber
Is humidity inside?	Ventilation
Is dust/sand inside?	Ventilation

Section 6: General Tips (After Sales)

6.1 Introduction

This section is divided into two parts. First part is considering after sales of the SWH systems installed within certain application where only some general tips are illustrated. Second part is related to assembly of evacuated tubes with storage tank to ensure good performance.

6.2 General Tips for After Sales of SWH Systems

In order to prevent bad reputation with solar water heating system, there is a need for the following:

- Elaborate procedure describing how to deal with complaints from the customers or installers
- Evaluate the complaints in such a way that appropriate corrective actions can be taken
- Have a record system for customer/installer complaints and corrective/ prevention actions
- Have the human competence to cover the after sales services.

Table 17 illustrates some general problems that commonly occur within the solar collector side where the problem is described with its cause and what could be the possible actions to be taken to solve it.

Table 17 Tips for solar collector problems solving [3]

Issue	Cause	Action
Condensation on the inner glass	• Defective joint collector • Clogging ventilation holes Vapor from insulation at stagnation temperature (200°C)	• Verify the joint quality and replace it • Unblock the ventilation holes • Control the quality insulation
Not hot water or not enough hot water	• Clogging tube grid • High thermal losses Insufficient area	• Verify diameter sizing tube and sizing area • Descale and clean the grid or cut the clogged pipe part, then weld it • Control the quality and thickness of insulation
Fluid leak	Corrosion of adaptor connecting	Replace with a non-corrosive material (stainless steel) or enameled coating
Broken glass	▪ Bad mounting of the glazing ▪ External thermal shock ▪ Internal thermal shock Weak resistant impact	• Verify the quality of glazing mounting • Opt. glass collector with EN 12975 standard

Table 18 illustrate some general problems that commonly occur within the solar collector side where the problem is described with its cause and what could be the possible actions to be taken to solve it.

Table 18 Tips for accessories problems [3]

Issue	Cause	Action
Not enough hot water in winter	• Thermostat set too low • Thermostat broken Defective electrical heater	• Replace the thermostat • Replace the electrical heater Set the thermostat (at 45°C)
No hot water at drawing point	Defective safety valve	Replace the safety valve
Low flow of hot water at drawing point	• Clogging safety valve Low system pressure	• Descale and clean the safety valve Check the correct pressure
Fluid leak	• Corrosion of brass adaptor connecting Defective joints	• Use non corrosive material for fittings Control the joint quality

Metal corrosion can occur as a result of multiple causes[1]

- Due to galvanic corrosion (ionization process), where dissimilar metals are coupled together and corrode rapidly when wet, especially in the presence of sea salt. In solar water heating systems, this is likely to occur between any of stainless steel, copper, steel, aluminium and zinc (galvanized steel). **The damage can be prevented by avoiding poor combinations of fasteners, framing, brackets and roof surfaces or using electrically isolating washers**.
- Galvanic corrosion can also occur when copper dissolved in water (such as the water out of a hot water storage tank overflow or header pipe) runs over a galvanized steel roof. This causes rapid corrosion of the zinc, obvious as highly localized rusting, and should be avoided by redirecting flow from copper pipes away from the metal roof.
- Waste metal from drilling left lying on a roof will cause corrosion. It is important to ensure the surface is left clean following installation.
- Using unsealed timber framing to support collector panels can increase risk of corrosion, as the wood will retain water against the roof or other metal surfaces, increasing time of any galvanic reaction.
- If collector panels have the same tilted angle as the roof, they can accumulate salts and dirt underneath that forming a highly corrosive electrolyte, breaking down protective corrosion products and causing rapid degradation. These areas need to be washed down with fresh water regularly. New Zealand metal roofing manufacturers recommend at least 100 mm clearance between collectors and metal roof cladding, and cleaning every 3 months in severe environments.
- An inert catchment effect can occur. The rainwater runoff from the glass covers of the flat plate collectors is pure, and the zinc of an unpainted galvanized roof under a collector will dissolve more readily in pure water than in water that already has some zinc dissolved into it.

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Annex 1

Exercise 1: Sizing the produced/used & the collector

A household of 4 persons consumes an average of 50 litres per person per day of hot water at 40°C. The temperature of cold water is 25°C. In order to cover this hot water need, we decide to install a SWH

1. Calculate the energy required in kWh/day of hot water for this household
2. Calculate the collector area necessary for this demand
3. Calculate the energy produced by the collectors in kWh/day
4. Calculate the energy conversion in kWh/day
5. Calculate the energy used in kWh/day

Given Data:

- Absorption coefficient of the flat: 0.9
- Transmission coefficient of glazing: 0.95
- Water density: 1,000 kg/m^3
- Heat capacity of water: 0.00116 kWh/kg.K
- System efficiency: 45%
- Collector efficiency: 75%
- Solar fraction: 70%
- Solar irradiation: 5 kWh/m^2.day

Solution:

1. $Q_{required} = \rho.V.C.(T_{hot}-T_{cool})$ = 1,000 X (50 X 4) X10^{-3} X 0.00116 X 15=3.48 kWh/day
2. $A_{col} = (Q_{used})/(I_{sol} . \eta_{syst}) = (Q_{required} .Fs)/(I_{sol} . \eta_{syst})$

   = (3,48 X 0.7)/(5 X 0.45)=1.08 m^2

3. Qi = A.I.(α. *t*) = 1.08 X 0.9 X 0.95 X 5=4.61 kWh/day
4. $Q_u = \eta_{col} . Qi$ = 0.7 X 4.27 =2.98 kWh/day
5. $Q_{used} = A.I. \eta_{syst}$ = 1.08 X 5 X 0.45 =2.43 kWh/day

Hot water needed according to existing parameters

Calculate the energy used Q_{used} (kWh/day) for these several capacities:

Volume	Energy Used (Qused) (kWh/day)
100	
150	
200	
250	
300	

Given Data:

- Water density (ρ): 1,000 kg/m^3
- Heat capacity of water (C): 0.00116 kWh/kg.K
- Solar fraction (Fs): 80%
- $\Delta T = (T_{hot}-T_{cool})$ = 20K

Solution

$Q_{used} = \rho.V.C.(T_{hot}-T_{cool}).\ Fs$

Volume	Energy Used (Qused) (kWh/day)
100	1.85
150	2.78
200	3.71
250	4.64
300	5.57

SWH specifications for Egyptian market

Calculate the collector area according to the energy used (m^2) for these several capacities:

Volume	Energy Used (Qused) (kWh/day)	Collector Area (Acol) (m^2)
100	1.85	
150	2.78	
200	3.71	
250	4.64	
300	5.57	

Given Data:

- Water density (ρ): 1,000 kg/m^3
- Heat capacity of water (C): 0.00116 kWh/kg/K
- Solar fraction (Fs): 80%
- ΔT = 20K
- Cairo solar irradiation (I_{sol}): 5 kWh/m^2.day
- System efficiency (η_{syst}): 35%

Solution:

$A_{col} = (Q_{used})/(I_{sol}\ .\ \eta_{syst})$

Volume	Energy Used (Qused) (kWh/day)	Collector Area (Acol) (m^2)
100	1.85	1.05
150	2.78	1.58
200	3.71	2.12
250	4.64	2.65
300	5.57	3.17

Capacity need for SWH type

The volume storage depends on several parameters:

- Production parameters
  - Solar irradiation
  - Area collector
- Consumption parameters
  - Quantity of hot water consumed per day
  - Temperature of hot water
  - Daily consumption profile

$V_{storage} = Q_{used} / [\rho.C.(T_{hot}-T_{cool})]$

For a first estimation and for an individual SWH:

$V_{Storage}$ = 30 - 50 Liter /Person/day

Exercise 2: Determination of the SWH capacity according to a family composition

A household of 6 persons needs domestic hot water. We decide to buy a SWH to cover this need. The solar irradiation of this location is 5.5 kWh/m^2.day and the temperature of cold water is 20 °C and hot water is 45°C

1. Estimate the storage volume needed if we suppose that one person consumes 50 L/day
2. Calculate the collector area corresponding
3. Recalculate the storage volume needed

If one day the solar irradiation is 9 kWh/m^2.day, the temperature inside the tank at the beginning of the day is 40 °C

4. What temperature is reached in the Tank in the end of the day? Consider that there is no hot water draw that day.

Given Data:

- Water density (ρ): 1,000 kg/m^3
- Heat capacity of water (C): 0.00116 kWh/kg.K
- System efficiency (η_{syst}): 35%
- Solar fraction (Fs): 80%

Solution:

1. $V_{storage}$ (estimated) = 50 X 6 = 300 Liter/day
2. $Q_{required} = \rho.V.C.(T_{hot}-T_{cool})$ = 1000 (50) (6) 10^{-3} X (0.00116 X15) = 8.7 kWh/day

   $A_{col} = (Q_{required} .Fs)/(I_{sol} . \eta_{syst})$= (8.7 X 0.8)/(5.5 X 0.35)= 3.61 m^2

3. $V_{storage}$ (calculated)= $Q_{used} / [\rho.C.(T_{hot}-T_{cool})]$ =

   =(5.5 X 0.35 X 3.61)/ [1000 X 0.00116 (45-20)] =240 L

4. $Q_{used} = A.I. \eta_{syst}$ = 3.61 X 9 X 0.35 = 11.37 kWh

   $\Delta T = Q_{used}/ (V_{storage}. \rho.C)$ = 11.37/ (0.24 X 1,000 X 0.00116) = 40.8 K

   T_{final} = 40+40.8 = 80.8 °C