



MATERIALS USED FOR MANUFACTURING **SOLAR** DOMESTIC HOT WATER SYSTEMS & COMMENTS ON THEIR RELIABILITY

A Review addressed to:
Manufacturers, Designers, Authorities



European Commission
Directorate General for Energy and Transport



ENERGIE PROGRAMME



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Table of Contents



FOREWORD	7
1. INTRODUCTION	7
2. SOLAR COLLECTOR	8
2.1 The Absorber	8
2.2 Absorber Coatings	9
2.3 Collector Transparent Cover	6
2.4 Collector Insultion	6
2.5 Collector Frame	7
2.6 Collector Sealants	8
2.7 Collector Qualification Testing	8
3. HOT WATER STORAGE TANKS	9
3.1 Glass E namelled Hot Water Storage Tanks	10
3.2 Galvanized Hot Water Storage Tanks	11
3.3 Use Of Thermosetting Resin-Bonded Lining Materials	12
3.4 Use Of Thermoplastic Coating Materials	12
3.5 Use Of Cement Coating	13
3.6 Internal Tank From Corrosion Resistant Material	13
3.7 Stainless Steel Storage Tanks	14
4. HEAT EXCHANGERS FOR SOLAR DHW STORAGE TANKS	14
5. HOT WATER STORAGE TANK INSULATION	15
6. AUXILIARY ELECTRIC HEATER	16
7. SOLAR DOMESTIC HOT WATER SYSTEMS	16
7.1 Heat Transfer Fluids And Expansion Tanks	17
7.2 Mountings	17
7.3 Connection Piping	17
7.4 Protection Against Freezing	18
8. SAFETY REQUIREMENTS	18
9. REFERENCES	18

Foreword

The content of this document is addressed mainly to Manufacturers, Designers, Retailers, Promoters, etc. of solar of domestic hot water systems. It may be also useful to Regional and Local Authorities.

A review is made in this report of the materials used for the construction of commercial solar domestic hot water systems. It has been written considering mainly the Mediterranean countries, which have a large potential of solar irradiation. In addition, comments are included for the reasons (engineering, investment, local conditions, etc.) leading to the selection of the specific materials.

All components of a solar domestic hot water system are covered, beginning with the solar glazed collector for thermal applications. The tank also is covered, because the temperature of the hot water from a solar domestic system can be higher (80°C - 95°C) than the one from water heater using electricity or a boiler (55°C - 60°C).

MATERIALS USED FOR MANUFACTURING SOLAR DOMESTIC HOT WATER SYSTEMS AND COMMENTS ON THEIR RELIABILITY

A review is made in this report of the materials used for the construction of commercial domestic hot water (DHW) systems, including collectors and hot water storage tanks. In addition, whenever possible, comments are made on reliability aspects and on reasons (engineering, investment, local conditions etc.) leading to the selection of the specific materials. A lot of work has been conducted and published since 1980 for solar collector design and materials considerations. Relevant material for the storage tank of a solar DHW system is considered standard engineering practice.

1. Introduction

Countries around the Mediterranean Sea have the climatic conditions allowing the design of DHW systems for direct use of the hot water (the auxiliary electric heater is turned on only when it is necessary). A large number of solar DHW systems have been installed in Cyprus, Greece and Israel. A strong solar market exists also in Europe (Germany, Austria).

Solar DHW systems can be direct (closed loop) or indirect (open loop) type (i.e. with or without heat exchangers in the hot water storage tank). Their operation is based on the thermosiphon principle or the use of a pump together with an appropriate control system.

A review is made in this report of the materials used for the construction of commercial solar domestic hot water systems. This report has been written considering mainly the Mediterranean countries, which have a large potential of solar irradiation, where simple thermosiphon systems are extensively used. In addition, comments are included for the reasons (engineering, investment, local conditions, etc.) leading to the selection of the specific materials.

A lot of work has been published since 1980 for (solar thermal glazed) collector design guidelines, including materials considerations (as an example, see references [1]-[3]). Relevant material for the storage tank of a solar domestic hot water system is considered standard engineering practice.

In this report, all components of a solar DHW system will be covered, beginning with the solar glazed collector for thermal applications. The tank also is covered, because the temperature of the hot water from a solar domestic system can be higher (80°C - 95°C) than the one from water heater using electricity or a boiler (55°C - 60°C).

2. Solar Collector

Flat plate, glazed, liquid heating solar collectors are employed in domestic water heaters. Design guidelines and materials considerations for the flat plate collectors are included in many publications (see references [1], [2] and [3]). Materials for the collector main components (absorber, absorber coatings, fluid passageways, transparent cover, insulation, frame and sealant) will be reviewed next.

2.1 The Absorber

An absorber may be made from a wide range of materials. Copper tubes is the most common material used for the fluid passageways, while mild steel or stainless steel and mild steel tubes are also in use. Tubes are bonded to an absorbing plate (a good thermal bond is required for tube and plate) from copper or aluminium or steel (mild or stainless).

The fluid passageways of the absorber are constructed from tubes bonded to an absorbing plate (fin). Tubes are readily available and anybody, with basic mechanics skills, can construct this absorber type. This absorber can withstand city water pressure. Bonding between tube and fin should resist both high temperatures and thermal cycling.

- The most common fin and tube arrangement employs copper tubing and copper fins, with appropriate welding (brazing, ultra-sonic, other).
- Another common fin and tube arrangement employs shaped sheet fins into which the tubes are fitted, but the fit should be "tight" for high collector efficiency. One particular design includes an aluminium profile (extruded) as a fin, where the copper tube is inserted in it and then expanded for perfect fit.
- Heavy duty galvanized steel pipes have been used in the "eighties" for the absorber in combination with steel absorber plate.

Absorbers of the "sandwich" type have been used and still are used. They are

consisting of two press formed (to create the internal fluid channels) steel sheets, which are spot and seam welded. The usual metal sheet thickness is 0.8mm-1.0 mm for mild steel or 0.5mm-0.7mm for stainless steel. The manufacturing process includes the press operation, welding, testing for leaks and painting. It is the same process as the one used for radiators of home heating systems (manufactured since many years). The relevant investment is justified only for some moderate production rates. Absorber has a good thermal efficiency. The use of corrosion inhibitors is required for the mild steel and good engineering practices can provide a reliable product. They are rather heavy, as compared with the ones made of copper and the thermal inertia is high.

2.2 Absorber Coatings

Matt **black paints** have been widely used as coatings of absorber surfaces for many years, because they are relatively cheap and simple to apply. Some form of pre-treatment of the plate surface is usually necessary to ensure satisfactory paint adhesion. It is important to note that well applied painting methods can withstand, without degradation, high temperatures and very severe condensations in the collector, due to frame deformations and cover tightness failures.

Black paints are strong emitters of thermal (infra-red) radiation and at high temperatures they produce significant heat losses from the front cover of the solar collector.

Collector heat losses can be substantially reduced by the use of **selective coatings**, which have a high absorptance for solar radiation, but a low emittance for thermal radiation. Good selective surfaces are expected to have an average absorptance of greater than 0.95 and an average thermal emittance of around 0.1.

Collectors with selective coating have high efficiency either in increased operating temperature of the collector or in locations with rather low irradiance. The specific application will determine the need for selective coating in the absorber.

Specialised companies produce the copper fin in rolls (of large width) with selective coating, which they cut to the width required by the individual collector manufacturers. Assurances should be required for the reliability of the selective coating (suitability to high temperatures, long life, preservation of the selective properties). The manufactures of the solar absorber have to combine (weld or "fit") the fin with the tubes.

Another commercially available product consists of aluminium fin with selective coating and with a copper tube combined to it. The product has a fixed fin width and it is sold in rolls. Solar collector producers have to cut it and to expand to copper tubes (with non-circular cross section) with compressed air.

It is to be noted that **semi-selective paints** are available in the market. They have lower emittance for thermal radiation than the black paints. They offer the advantage of collectors with relatively high efficiency with moderate increase in the cost.

Companies exist that are specialized in the production of absorbers (black paint or selective coating), which they sell to interested parties.

2.3 Collector Transparent Cover

The most widely used transparent cover material in solar collectors is the **common glass**, which has most of the required properties. It is readily available everywhere, its cost is reasonable, but it is rather heavy and brittle. Thickness is in the range of 3 mm to 4 mm and glass areas of 2m² are common. The green appearance is due to the iron content of the glass, which reduces its solar transmittance.

“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) and also it has 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 during its use.

Tempered glass is more expensive than the common glass and it is ordered in its final dimensions to the glass producer. It can not be cut after delivery. Solar collector manufacturers have to locate the tempered glass producer and investigate the delivery time, which can be long (need for reasonable sales forecast for each collector size or increased stocks that is expensive).

The method of supporting the glass (common or tempered) on collector frame should consider the thermal expansion of the glass. It is necessary to leave an appropriate space around the entire edge of a glass cover in order to ensure that the greater thermal expansion of the cover (over the metal collector frame) is handled. The use of sealant material should also be combined with the proper glass support

Plastic transparent covers exist that have resistance to the ultra-violet degradation and degradation from the exposure to high temperatures. Some use is made of non-reinforced rigid plastic covers of convex shape (to increase rigidity) and some of these collectors contain a thin plastic film as an inner glazing. Other plastic cover designs (double sheets) are also available.

2.4 Collector Insulation

Heat losses from the back and sides of a collector are reduced by the use of insulation. It should be resistant to the maximum stagnation temperature of the collector usually about 150°C in collectors with matt black paint absorbers and about 200°C when selectively coated absorbers are used. At these high temperatures the insulation should not shrink, melt, or give off vapours ("outgas"), which could condense on the collector cover and reduce its solar transmittance.

In order to reduce the costs, a thin layer of temperature-resistant insulation (possibly mineral wool) is used in contact with the absorber or close to it and the remaining thickness is filled with a less expensive, low temperature insulating material. Because of the risks of water penetration in solar collectors, consideration should be given to insulation resistance to the water, and its thermal conductivity properties and durability in the presence of moisture.

Polyurethane is employed in collectors but not as frequently as in storage tanks. Often polyurethane is used to enhance the rigidity of the collector (30-35 mm thickness). In this case expensive molds are required, which should sustain the pressure from the expanded polyurethane foam (forced to take a specific shape). An air gap behind the absorber, together with a reflecting foil on the insulation (necessary also for the manufacturing process) protect insulation materials from exposure to high temperatures. Consideration should be given to the thermal expansion of the polyurethane, which is many times higher than the one of the mild steel (long sides of the frame may have to be connected by appropriate "links").

Polyurethane is also available in sheets with reflecting foil. Sheet thickness and dimensions vary.

Glass fibre is another common material. It does not require any investment and it is favored in case of very small production rates. Its insulating properties deteriorate with the presence of water or moisture. It should be supported, ventilated and prevented from blocking drainage or ventilation holes. Mineral wool is used as an alternative to glass fibre for higher temperatures, but it is more expensive.

2.5 Collector Frame

The frame provides the structural stiffness in a collector (in some collectors polyurethane 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 back panel in most cases is aluminium sheet, but galvanized steel sheet is also used (thickness of the order of 0.5-1.0 mm).

Another approach (not quite often) is to construct the whole frame by vacuum-formed sheet of ABS (acrylonitrile-butadiene-styrene). ABS with special treatment provides reasonable resistance to weathering.

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 to ensure that it will not deform under service conditions (long sides of the frame have even to be connected by appropriate "links").

Water-tightness between the frame and the transparent cover is very important for the collector reliability.

Because of the risks of water penetration in solar collectors with aging (and not only), it may be considered preferable that the casing is designed with drain holes and possibly with adequate ventilation. At the same time provision should be taken to prevent insects from entering the collector

2.6 Collector Sealants

The integrity and long term durability of a collector depends strongly on the design and the quality of the sealing assembly around the cover and around the fluid inlet and outlet pipes.

The sealants need to be resistant to the temperatures involved and to weathering. They should remain flexible in order to ensure water-tightness and to permit thermal movement of the collector components throughout the expected lifetime of the collector. They also must remain firmly in place. Pre-formed cover sealants should be kept in place (and also protected from solar radiation and attack by birds) by a separate aluminium profile.

EPDM (Ethylene Propylene, Diene Monomer) is commonly used in collectors. It is relatively expensive, but it has good temperature and weathering resistance. Silicone sealants are also used, because they are durable over a wide range of temperatures and they have good resistance to atmospheric ageing. Curing period should be considered in the production process.

2.7 Collector Qualification Testing

A series of tests are included in the standards shown in references [11] and [12]. The "Rain Penetration" test and the "Exposure" test are very important ones. The manufacturer can conduct both of them without any difficulty, and he can obtain very useful information for the collectors under consideration.

For the **rain penetration** test, the collector is not filled and the inlet and outlet fluid pipes of the collector are sealed. It is placed in a tilt of 30° - 45°. The collector is sprayed on all sides with water for some period. Having the collector facing the sun, any rain penetration will be apparent by the condensation of water inside the glazing. In case of water penetration, investigation should be conducted to determine the point of entry of the water.

The **exposure** test provides a low-cost indication of the aging effects, which are likely to occur during a longer period of natural aging. The collector is mounted outdoors, but is not filled with fluid. All of its fluid pipes are sealed to prevent cooling by natural circulation of air except one, which is left open to permit free expansion of air in the absorber.

The collector is exposed to the sun for a period of four or five weeks under some reasonable irradiation conditions. At the end of the exposure test, the collector is inspected for damage or degradation related to glazing, insulation, absorber surface and the design of the whole collector.

3. Hot Water Storage Tanks

Hot water storage tanks (solar applications, conventional heating by electric heaters or other means) are designed considering pressure requirements. Corrosion protection is the other important design parameter. It is to be noted that the capacity of the tanks for simple (thermosiphon) solar domestic hot water is usually in the range from 120t to 200t.

Mild steel is the most commonly used material for the storage tanks, because it has the strength for the pressure requirements (6 bars or more) for wall thickness of 2mm-3mm. Corrosion protection, in the water side of the tank, is achieved by appropriate coatings like

- glass enamelling
- galvanizing
- thermosetting resin-bonded lining materials
- thermoplastic coating materials
- cement coating

or by the use of an internal tank from corrosion resistant material (thin copper sheet, polymer, other).

Materials, resistant to hot water corrosion, that have been used for tank construction are **stainless steel** and **copper** (interest has been diminished for copper due to high prices).

It is necessary to point out that the water temperature in the solar storage tank can easily reach, during summer, 70°C-80°C, during regular use of the system or as high as 100°C when it is not used (weekends or summer vacation periods).

The hot water temperatures of solar domestic hot water systems are higher than those of conventional water heaters. In electric water heaters, for example, maximum temperature is controlled by a thermostat, which is usually set at 60°C.

The higher temperatures in solar domestic hot water systems require special attention to the design of the storage tank against corrosion.

Standards, in different countries, cover the construction of the tank and also methods for corrosion protection in the water side. References [4]-[9] are relevant German standards. Final details of tank design depend on the corrosion protection method.

One important item in tank design is that the corrosion protection coatings should satisfy the requirements with regard to physiological suitability according to the current state of the art.

Another issue in the tank design, that needs special attention, is the cold water inlet and hot water outlet piping. They should not present any problem in corrosion protection method and at the same time the cold water entering the tank should not destroy the temperature stratification of the hot water. In the standards, shown in references [13] and [14], a special testing is foreseen for determining the mixing conditions during the draw off of hot water from the tank. This test can be conducted by the solar producer relatively easily.

Storage tank manufacturers have established business in many countries. The tanks are sold either for electric or solar applications. The corresponding buyer (solar manufacturer) fits insulation, outer cover, and other accessories to the tanks and adapts them to his product line.

3.1 Glass Enamelled Hot Water Storage Tanks

Enamelling has been a valuable protection against corrosion for steel. It has been used for hot water storage tanks first in the U.S.A. This development started in Europe somewhat later with the raising of the water temperature above 60°C. Until then, the materials used were galvanized steel, copper and stainless steel alloys. It is to be noted that the zinc layer loses its protective action for the steel rapidly for temperatures above 65°C.

In Europe, enamelling of the hot water storage tanks is made as single-unit hollow vessels, which (vessels) require some structural adaptations for the enamelling process. Special attention should be given during the construction of the tank so that all its internal side (i.e. the side to be enamelled) to be as smooth as possible. Irregularities within the zone of welds, in the inside of the tank, should be smoothed by grinding, followed by sand blasting. It is recommended that all these welds to be done from the inside of the tank in order to achieve smoothness.

The enamelling process includes pickling, which is the metal surface pre-treatment in order to accept the enamelling. The enamel is deposited by pouring "slurry" (ground enamel frit, other additives and water) on the inside walls of the vessel (largely automated process). The "biscuit" (after drying) is brushed off the sealing and threaded areas. Firing at a temperature of approximately 850°C is the last step in application of enamel coating on steel tanks.

Enamel is applied in two coats, the ground (adhesion with steel) and the cover coat (sustains hot water corrosive action). Enamelling thickness should be in the range of 0.250-0.400 mm. It is to be pointed out that not all steels are suitable for enamelling (special request should be made to the steel mill). Direct-on enamels (i.e. only one coat) are also available.

Many years of established experience has shown that properly constructed and enamelled storage tanks with a magnesium anode (it protects areas that might not be covered with enamel) represent reliable products with long life (decades). It is only necessary to inspect regularly (especially in the beginning) the function of the anode. Tanks have been designed for pressures of 10 bars or even higher.

Example of a standard for tank construction is reference [4], reference [5] is a standard relevant to glass enamelling, while reference [7] is a standard that covers the cathodic protection of enamelled steel tanks against corrosion (use of a proper anode).

Enamelling facilities require high investment. Almost three shifts per day are necessary in order to achieve product enamelling at reasonable cost. Facilities, existing in many countries for enamelling conventional products, can be modified to accept steel storage tanks.

3.2 Galvanized Hot Water Storage Tanks

Zinc has been utilized to extend the life of steel by galvanizing. Galvanized steel has been used for many years for electric hot water storage tanks. Its main drawback is the fact that the zinc coating loses its protective action at the temperature range of 60°C-85°C. In the middle of this range the rate of zinc loss is very high (more than 100 times at lower temperatures). This temperature range can easily be achieved in solar DHW systems and so there are obvious restrictions in its use. Electric hot water heaters with a thermostat setting at 55°C-60°C, made of galvanized steel, have been used for many years and are considered reliable.

In the early stages of solar domestic hot water systems development, galvanized tanks have been used because they were readily available and other protective methods were not economically justified (low production rates). Galvanized tanks can be used in solar DHW systems in the cases that hot water temperature in the tank can be kept below 60°C (continuous use of hot water, low efficiency collectors).

The recommended procedure is to construct the tank from mild steel and then galvanize it by hot dipping. Relevant German standard is reference [10]. One other common practice is to use galvanized metal sheet of thickness usually 3mm. In this case, special attention should be given to the welds.

3.3 Use Of Thermosetting Resin-Bonded Lining Materials

The lining material, used for corrosion protection of the water side of steel hot water storage tanks, is thermosetting resin-bonded products especially developed for this purpose. Application and heat treatment of these linings are to be performed as suggested by the lining material manufacturer. The water side vessel surface preparation includes a compressed air sand blasting (use of metallic particles). Irregularities within the zone of welds should be smoothed by grinding before blasting. The lining is applied continuously and uniformly by spraying, brushing, dipping or flooding. Usually, several layers are required that are applied and post-treated separately (temperatures of 150°C-200°C have been reported). Relevant German standard is DIN 4753.4 (Ref. [6]).

Lining has a minimum thickness of 0.250mm and it can sustain temperature exceeding 95°C (no specific temperature has been reported by solar product manufacturers). Actually one of the tests in reference [6] requires the vessel to be subjected to 1000 periodical temperature changes between approx. 15°C and a maximum water temperature of approx. 95°C.

The relevant investment is not very high and the method can be applied to relatively moderate production rates.

3.4 Use Of Thermoplastic Coating Materials

This method is more known as plastic coating of the water side of steel hot water storage tanks. The same method is used for other objects. Material, that is used for this purpose should be physiological inert and be approved for direct contact with food. A pore-tight coating is required for the tank corrosion protection, which is achieved by a special manufacturing process.

This process includes grinding of irregularities within the zone of welds, a compressed air blasting with metallic particles and application of a special primer. Next, the temperature of the tank is raised at approx. 260°C and the plastic material is applied in the form of powder to the tank internal surface, with the help of special equipment. Plastic coating thickness should be higher than 0.300 mm and a recommended mean value is 0.350 mm.

Relevant is the German standard DIN 4753.9 (Ref. [9]). It is to be pointed out that a maximum water temperature of 85°C is mentioned in the standard. In solar domestic hot water systems, that can develop higher temperature, there is a need to reduce it by the use of a proper thermostatic valve that allows water out from the storage tank (not always a safe process). The method can be applied to systems where temperatures do not exceed 85°C.

As in thermosetting materials, the relevant investment is not very high and the method can be applied to relatively moderate production rates.

3.5 Use Of Cement Coating

Another method, that has been employed rather rarely for the corrosion protection of steel hot water tanks, is coating the inner surface of the tank with cement (special cement with appropriate resins). Its thickness is approximately 5 mm and it is applied in two layers (24h drying period for the first layer). The cement coating adds weight to the tank and it might create problems to installers.

3.6 Internal Tank From Corrosion Resistant Material

Corrosion protection of hot water storage tanks, made of mild steel, can be achieved also by the use of an internal tank made from corrosion resistant materials. Thin copper sheets (northern Europe) and polymer materials (Europe, U.S.A.) have been used for the construction of the internal tank.

The outside shape of the internal tank is similar to the inside shape of the mild steel tank. The pressure of the hot water inside the internal tank is transferred to the outside metallic tank. The metallic tank does not come in contact with the hot water and so it is protected from its corrosive action.

The material of the inner tank should withstand the expected high temperatures of the hot water and should be physiological inert and be approved for direct contact with food.

Special measures should be taken in order to avoid the development of vacuum inside the internal tank when hot water is used. Installation of a vacuum breaker in the cold water supply line is one of them.

3.7 Stainless Steel Storage Tanks

Stainless steel can be used for the construction of hot water storage tanks. The

main problem is chloride stress-corrosion cracking failure. The proper quality of stainless steel to withstand this kind of failure is rather expensive. In addition, the welding process is considered sophisticated and special equipment and experience are necessary.

4. Heat Exchanger For Solar DHW Storage Tanks

All solar domestic hot water (DHW) systems of closed type require a heat exchanger in the solar storage tank, which of course adds cost to the systems. However the closed type, in which a separate (from the hot water) heat transfer fluid is used to carry heat from collector to the heat storage system, allows a wider choice of materials in the solar absorber and system pipework, because anti-freeze and corrosion inhibitors can be added to the fluid.

The **double-wall** (or jacket) design of heat exchanger has been used extensively with glass enamelled tanks, but its use has not been limited there. It provides a large exchange area and its construction is relatively easy. The distance between the walls is very critical to the "inertia" of the solar system. Corrosion protection of steel in the heat exchanger area (i.e. between the two walls or jackets) is very important, because of the high temperatures, the possibility of "free" space (not covered by fluid) at the top of the exchanger and the presence of highly corrosive steam (under certain conditions).

A double wall tank needs additional attention, when glass enamelling is involved (actually the firing process at 850°C):

- The outer wall should include some round groove(s) in order to avoid deformation.
- Measures should be taken to avoid development of iron oxides in the space between the two walls.

Heat exchangers inside the tank is another alternative. Consideration should be given to the corrosion protection of the main tank and the heat exchanger itself. The thermal efficiency of the closed system as a function of the time (deposits on the water side of the exchanger) is an issue to be addressed. The support of the heat exchanger, as well as the connection to the solar collector should be properly considered.

Copper tubes with two headers have been used for heat exchangers inside the tank. Another design is made from a copper or steel pipe (galvanized or glass enamelled) of small diameter, shaped in a helical form.

An expansion tank and pressure relief valves should be incorporated to the “closed” system.

5. Hot Water Storage Tank Insulation

In specifying insulation requirements for storage tanks of solar domestic hot water systems, consideration should be given to the fact that the tank is installed outdoors and that the insulation will be in contact with the vessel, whose temperature may exceed 100°C (especially in the double-wall tanks).

Polyurethane (insulation in the form of expanded foam) is employed exclusively by all manufacturers with thickness ranging between 50 mm and 70 mm. Thickness of 50 mm is considered adequate. The circular form of the tank is very convenient for the construction of the required molds at relatively low cost.

It is very important to minimize **thermal bridges** between the hot tank and the outside protection cover and also between the hot tank and the support frame.

One of those is the area close to the mounting of the electric heater and the thermostat (electric heater flange). The design of insulation there should consider the special safety features of the thermostat. A thermostat includes the operating contact, which controls the hot water temperature (40°C - 60°C), when electricity is used. It is also equipped with a second one (for safety), which operates (trips) when hot water temperature exceeds a certain limit (usually 90°C - 95°C). High temperatures, during summer, may trip this safety contact. Such an event will require the visit of a technician to restore it in autumn, so that the back up electrical heater can be operational again.

In the standards, shown in references [13] and [14], a special testing is foreseen for determining the **heat losses** of hot water storage tank. In case of a thermosiphon, the testing determines also the presence of reverse flow conditions

6. Auxiliary Electric Heater

Usually, an auxiliary electric heater is installed in solar domestic hot water systems and its size is in the range of 2 KW to 4 KW. A size of 3 KW or even smaller is recommended for the solar systems. The electric resistance wire is inside copper tubing with appropriate electric insulation. The tube in the water side is either galvanized or tin-coated. Attention should be given to minimize the power per unit length of the heater (i.e. making it longer) in order to increase its reliability.

The location of the electric heater inside the tank is usually close to the hot water outlet (near the top in vertical tanks or at the side in horizontal tanks) so that the heater provides energy only to a part of the tank water (when the heater is on). The thermostat setting should be as low as possible (lower than 50°C).

The electric heater and the thermostat are mounted on a flange that is attached to the vessel with screws. The flange opening should have a diameter greater than 100 mm so that the inside surface of the vessel can be inspected (during manufacturing and later) and cleaned from deposits (during operation).

7. Solar Domestic Hot Water Systems

The most common application for solar flat plate collectors is for heating domestic hot water (DHW). The solar DHW system consists of the storage tank, the collector(s), pipework, valves, mounting frame, sometimes pump and control, and finally transfer fluid and expansion tanks in closed type (with heat exchangers) systems.

Natural circulation systems known as thermosiphons, operate without pump and the collectors are mounted below the level of the storage tank. Appropriate height (approx. 25 cm) between tank and collector(s) or non-return valve, with very low opening pressure, can be employed to prevent reverse circulation and resultant night time thermal losses ("bursts" of hot water from the tank or heat transfer fluids return to the collector and cooling takes place there). Thermosiphons usually are closed type with heat exchangers (indirect systems).

Finally, in "Integral Collector Storage" systems the storage tank(s) functions simultaneously as collector. These systems are efficient when hot water is drawn during the day. Their night losses are very high from the front transparent covers.

7.1 Heat Transfer Fluids And Expansion Tanks

One important aspect of domestic hot water system design is to ensure corrosion protection of the absorber fluid passageways, the connecting piping between collector(s) and tank and finally, in a closed system, the heat exchanger.

Copper, can be used without the need for precautions against corrosion. Mild steel fluid passageways should always be protected by using an indirect system with appropriate corrosion inhibitors in the thermal transfer fluid.

Usually water is used together with corrosion inhibitors and proper anti-freeze (components should be mixed outside the DHW system). Alternatively, ready mixed fluids are available. Consideration should be given to the extreme temperatures that may exist under stagnation conditions (fluids may break up, forming organic acids) and the fact that fluids may be toxic. Regulation might exist to protect consumers from toxic fluid additives in the event of heat transfer fluid leakage to the hot water. In some countries ethylene glycol is prohibited, though propylene glycol may be used as anti-freeze. The usual practice is that manufacturers recommend or offer thermal transfer fluids suitable for their solar products.

Attention is attracted to the thermal expansion of the heat transfer fluids in a closed type domestic hot water system. In most cases it is necessary to employ an expansion tank. Since the volumetric expansion of antifreeze solutions is greater than the volumetric expansion of water, systems using antifreeze require larger expansion tank than do systems using water.

7.2 Mountings

Solar domestic hot water (DHW) systems are installed on flat roofs or on the ground beside a building on free standing frames, that are part of the product line of a specific manufacturer. Specially designed frames are used when the DHW system has to be installed on a sloping roof (difficulties in installing, inspecting and maintaining).

Mountings should be designed considering the expected load conditions from wind or other loads appropriate for the areas, where they will be used. The involvement of a civil engineer is recommended.

Mild steel frames should be protected from rusting either by galvanizing or painting, but in both cases reliable pre-treatment of the frames is essential.

7.3 Connection Piping

Connecting piping between the different components of a solar domestic hot water (DHW) system usually are sold as a set by the corresponding manufacturer.

The manufacturer should consider material compatibility regarding corrosion, proper insulation, proper design against air locks (i.e. use of automatic air bleeds, geometry, etc) and avoidance of leaks. Insulation should be covered by appropriate coating to avoid degradation due to solar radiation and it should be used to cover all piping.

It is important to apply basic plumbing rules in connecting the solar DHW system with the user's facilities

7.4 Protection Against Freezing

Closed type solar domestic hot water (DHW) systems rely reliably on antifreeze to avoid freezing.

There are two basic ways to protect against freezing of an open type DHW system

- provide means for draining the system
- provide a thermostatic valve to allow continuous low flow of domestic water though the system but difficulties have been encountered in both.

8. Safety Requirements

The solar domestic hot water tank equipped with an electric heater should conform with certain standards related to protection of user against electric shocks and against tank explosion in case of failure of interruption of electricity for any reason. Laboratories in different countries can test tanks for the previously mentioned features and issue relevant testing report.

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