EXPERIMENTAL INVESTIGATIONS ON SMALL LOW FLOW SDHW SYSTEMS BASED ON MANTLE TANKS

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ABSTRACT

Side-by-side tests of two small SDHW systems based on mantle tanks have been carried out in a laboratory test facility. The systems are identical with exception of the vertical mantle tank. One of the tanks is the so-called Danlager 1000 marketed by Nilan A/S. The other tank is a test tank produced by METRO THERM A/S. Both tanks are built into 60 x 60 cm cabinets. In this way it is possible to bring the test tank on the market. Both hot water tanks have a total volume of 189 l and an auxiliary volume of 86 l at the top of the tank heated to 51°C by a 1000 W electrical heating element during the tests. The hot water tank diameter is 492 mm and 400 mm for the Danlager 1000 tank, respectively the test tank. The height/diameter ratio for the hot water tank is 2.1 for the Danlager 1000 tank and 3.9 for the test tank. The mantle inlet for the Danlager 1000 tank is located at the very top of the mantle, while the mantle inlet for the test tank is located 125 mm from the top of the mantle. Both tanks are insulated with PUR foam insulation filling up the space between the tanks and the cabinets. Consequently the insulation thickness for the test tank is greater than the insulation thickness of Danlager 1000.

The tests were carried out with the same daily hot water consumption of 100 l/day. Measurements of the thermal performance of the systems have been carried out for more than one year. The measurements show that the thermal performance of a SDHW system can be increased by about 15% by replacing the marketed tank with the test tank.

It is thus documented that marketed mantle tanks can be strongly improved by increasing the height/diameter ratio, by increasing the thickness of the side insulation and by lowering the position of the mantle inlet.

Keywords: solar domestic hot water systems, low flow, laboratory test, mantle tank design

1. INTRODUCTION

Small solar domestic hot water systems based on vertical mantle tanks, as schematically shown in figure 1, have a number of advantages compared to similar solar domestic hot water systems based on hot water tanks with a built in heat exchanger spiral [1].

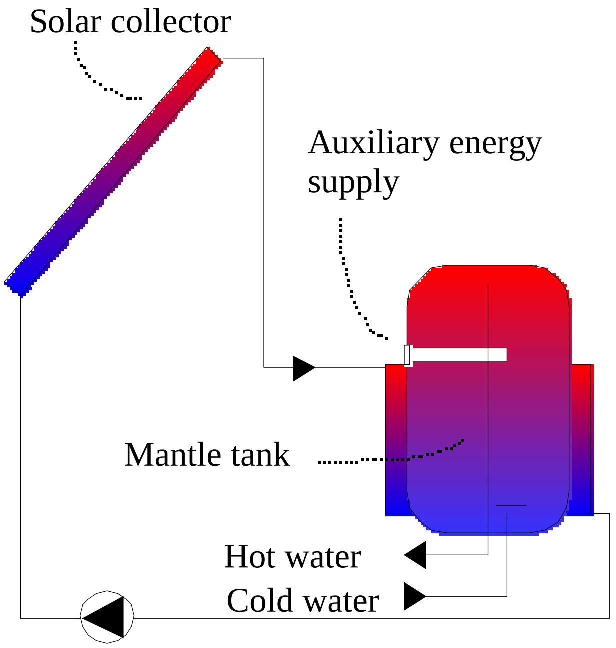

Fig. 1. Schematic illustration of SDHW system based on a mantle tank.

The advantages are:

- The yearly thermal performance is increased by 10%-25% depending of the solar fraction. The increased thermal performance is caused by the thermal stratification established in the mantle tank during the operation of the solar collectors.
- Lime deposits in the mantle tank are a factor of 2.5 lower than the lime deposits in a similar hot water tank with a built in heat exchanger spiral. Sooner or later the lime deposits, which are located at the bottom of the tanks, will cover a part of the heat exchanger spiral resulting in a decreased heat exchange capacity rate, an increased collector temperature, a decreased collector efficiency and critical high solar collector fluid temperatures. These problems will not occur in the mantle tank.
- If low volume flow rates are used instead of high volume flow rates in the solar collector loop the extra thermal performance of mantle tank systems can additionally be somewhat increased. Further, small pipe dimensions can be used in the solar collector loop if low flow rates are used. Therefore the installation can be facilitated. For instance, small all-in-one solutions with two small pipes, pipe insulation and a wire for the control system can be used as solar collector loops. In this way the cost of the solar heating system can be decreased and the thermal performance of the solar heating system can be further increased due to reduced heat loss from the pipes of the solar collector loop.

The above mentioned good reasons to use mantle tanks as hot water tanks for small solar domestic hot water systems have been known for many years. Further, recent theoretical investigations showed that it is possible essentially to increase the thermal performance of low flow solar domestic hot water systems based on Danish marketed mantle tanks by relatively simple design changes of the tanks [2]. The thermal performance can be strongly improved by:

- Increasing the height/diameter ratio of the mantle tank
- Reducing the height of the mantle
- Increasing the thickness of the insulation material on the tank side
- Placing the mantle inlet at a level somewhat lower than the upper mantle level
- Using a tank material with a lower thermal conductivity than steel

Of course it is of special interest that the thermal performance can be increased by reducing the mantle height. In this way it is possible to decrease the costs of mantle tanks.

2. EXPERIMENTAL INVESTIGATIONS

In order to document that marketed mantle tanks can be improved as mentioned above, tests were carried out in a laboratory test facility for solar domestic hot water systems at the Technical University of Denmark. Two small low flow solar domestic hot water systems based on mantle tanks were tested side-by-side in the test facility. The systems are identical with exception of the mantle tanks. The most important data for the systems are shown in table 1.

The hot water tanks used in the systems are the marketed vertical mantle tank Danlager 1000 from Nilan A/S and a vertical test mantle tank produced by METRO THERM A/S. Danlager 1000 is considered as the best hot water tank for small solar domestic hot water systems on the Danish market. Both tanks have a domestic water volume of 189 l and an auxiliary volume of 86 l at the top of the tanks. During the test period the auxiliary volumes are heated to 51°C of an electrical heating element with a power of 1000 W.

For both mantle tanks the tank material is steel. Both tanks are built into a 60 x 60 cm cabinet. The height of the cabinet is 181 cm for Danlager 1000 and 197 cm for the test tank. Figure 2 shows a photo of the two tanks used in the investigations. The most important data for the two mantle tanks are shown in table 2.

TABLE 1: Data for the two tested solar heating systems

Solar collector manufacturer	Arcon Solvarme A/S
Solar collector type	ST-NA
Solar collector area	2.51 m²
Maximum collector efficiency	0.801
Collector heat loss coefficients	3,21 W/m²K and 0.013 W/m²K²
Incidence angle modifier for collector	3.6 (tangent equation)
Collector orientation	South facing
Collector tilt	45°
Solar collector loop	33 m 10/8 mm copper pipes
Volume flow rate in solar collector loop	0.5 l/min
Solar collector fluid	40% propylene glycol/water mixture
Location	Technical University of Denmark, Kgs. Lyngby, Denmark. Latitude: 56°N

Fig. 2. Photo of the two tanks used in the experiments.

TABLE 2: Data for the two mantle tanks of the solar heating systems

Tank	Danlager 1000	Test tank
Outer diameter of hot water tank	0.492 m	0.400 m
Height/diameter ratio of hot water tank	2.1	3.9
Mantle gap	0.0115 m	0.0200 m
Mantle height	0.395 m	0.600 m
Heat transfer area, mantle	0.61 m²	0.75 m²
Water volume above upper mantle level	97 l	110 l
Mantle inlet	Top of mantle	0.125 m from top of mantle
Thickness of hot water tank wall	0.0030 m	0.0025 m
Thickness of mantle wall	0.0025 m	0.0025 m

The test tank design is determined based on calculations with the detailed simulation program MANTLSIM [3]. MANTLSIM is used to calculate the thermal performance of solar domestic hot water systems with differently designed mantle tanks.
The test tank has a smaller diameter than Danlager 1000 and correspondingly a higher height. The height/diameter ratio is 3.9 for the test tank and 2.1 for Danlager 1000. The thickness of the insulation material for the side of the tank is larger for the test tank than for Danlager 1000, since the space between the tank and the cabinet for both tanks are filled up with PUR foam. Finally, the mantle inlet for the test tank is placed 12.5 cm below the top of the mantle, while the mantle inlet for Danlager 1000 is placed at the top of the mantle.

3. MEASURED THERMAL PERFORMANCE

The two solar heating systems have been tested under the same test conditions in the test period March 12, 2006 – May 22, 2007: The solar radiation on the two collectors is the same and the hot water consumption and hot water consumption pattern are the same for both systems. Daily a hot water volume of 100 l, heated from 10°C to 50°C, is tapped from each tank. Hot water is drawn from the tanks at 7 am, at noon and at 7 pm in three equally sized volumes. The hot water consumption is 32.2 kWh per week.

The tapped energy, the auxiliary energy and the solar heat transferred to the heat storage are measured for each system during the whole test period.

The monitoring system had failures in some of the weeks during the test period. In the year May 08, 2006 – May 08, 2007 measurements of the thermal performance of the two systems were carried out in 40 weeks. Most of the weeks with failures of the monitoring system appear in the autumn 2006. The measured results for the 40 weeks are shown in table 3. The net utilized solar energy is the tapped energy minus the auxiliary energy transferred to the top of the tank by means of the electrical heating element. The solar fraction is the ratio between the net utilized solar energy and the tapped energy.

TABLE 3: Measured energy quantities in 40 weeks in the test period May 08, 2006 - May 08, 2007

Measured energy	Solar heating system with Danlager 1000	Solar heating system with test tank
Solar radiation on solar collector	2270 kWh	2270 kWh
Tapped energy	1289 kWh	1289 kWh
Auxiliary energy to top of tank from electrical heating element	738 kWh	664 kWh
Solar heat transferred to hot water tank	780 kWh	814 kWh
Net utilized solar energy	551 kWh	625 kWh
Solar fraction	43 %	49%

It is seen that the thermal performance of the solar heating system with the test tank in the 40 weeks test period is 13% higher than the thermal performance of the solar heating system based on Danlager 1000.

Figure 3 shows the performance ratio, defined as the ratio between the net utilized solar energy for the solar heating system based on the test tank and the net utilized solar energy for the solar heating system based on Danlager 1000, as a function of the solar fraction for the solar heating system based on Danlager 1000. Each point in the figure represents the performance ratio for one week. For instance, a point with a solar fraction of 0.50 and a performance ratio of 1.20 corresponds to a week where the thermal performance of the solar heating system with the test tank is 20% higher than the thermal performance of the solar heating system with Danlager 1000 and where the solar heating system with Danlager 1000 covers half of the hot water consumption.

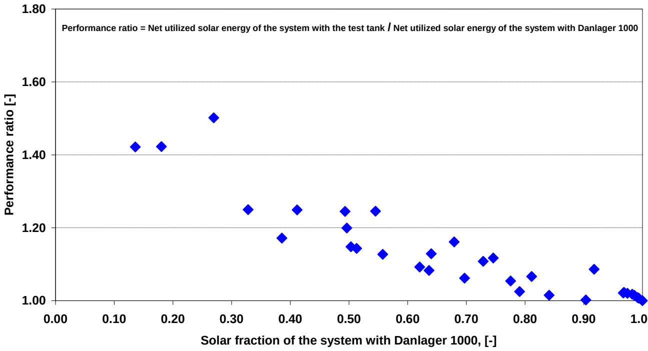

Fig. 3. Performance ratio for the solar heating system with the test tank as a function of the solar fraction of the solar heating system with Danlager 1000.

The extra thermal performance of the solar heating system with the test tank is strongly influenced by the solar fraction. The extra thermal performance is increasing for decreasing solar fraction. The thermal advantage of the test tank is therefore highest in the winter period, in less sunny periods of the year and in periods with a high hot water consumption.

Based on the measurements it is estimated that the extra yearly thermal performance, without problems with the monitoring system, would be 15%.

4. CONCLUSION

The investigations have documented that relatively small design changes of a marketed mantle tank can result in relatively large increased thermal performance of a small solar domestic hot water system.

It is recommended to design mantle tanks built into 60 x 60 cm cabinets with high height/diameter ratios, with increased side insulation thickness and with a mantle inlet position somewhat lower than the top of the mantle.

Hopefully, improved mantle tanks will soon be brought onto the market.

5. REFERENCES

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