# Pressure and temperature development in solar heating system during stagnation

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**Abstract**

This paper presents an investigation of stagnation in solar collectors and the effects it will have on the collector loop. At a laboratory test stand at the Technical University of Denmark, a pressurized solar collector loop was designed to test different numbers of collectors and different designs of the pipes of the solar collector loop. During the investigation the pre-pressure of the expansion vessel and system filling pressure was changed.

The investigations showed that a large pressurised expansion vessel will protect the collector loop from critically high temperatures as long as the solar collectors have a good emptying behaviour and the circulation pump is turned off during stagnation.

Keywords: Stagnation, Solar collector loop.

## 1. Introduction

As part of an Energy Research Project "Quality insurance of solar heating system – Part III" the effects of stagnation in solar collectors were investigated in cooperation with Batec Solvarme A/S.

The aim of the project was to elucidate how stagnation in the solar collectors affects the solar collector loop, the solar collector fluid and the expansion vessel. As part of the project a dimensioning tool was also developed to determine the size of a pressurized expansion vessel for a solar collector loop in a solar heating system, which in sunny periods is protected from critical high temperatures by turning off the circulation pump if the temperatures are higher than a certain level.

## 2. Experimental setup

Three flat plate solar collectors are installed in the collector loop along with a pressurised expansion vessel. The collector loop is designed so that it is possible to test different inlet connections to the collectors and different numbers of collectors, see Fig. 1, top left.

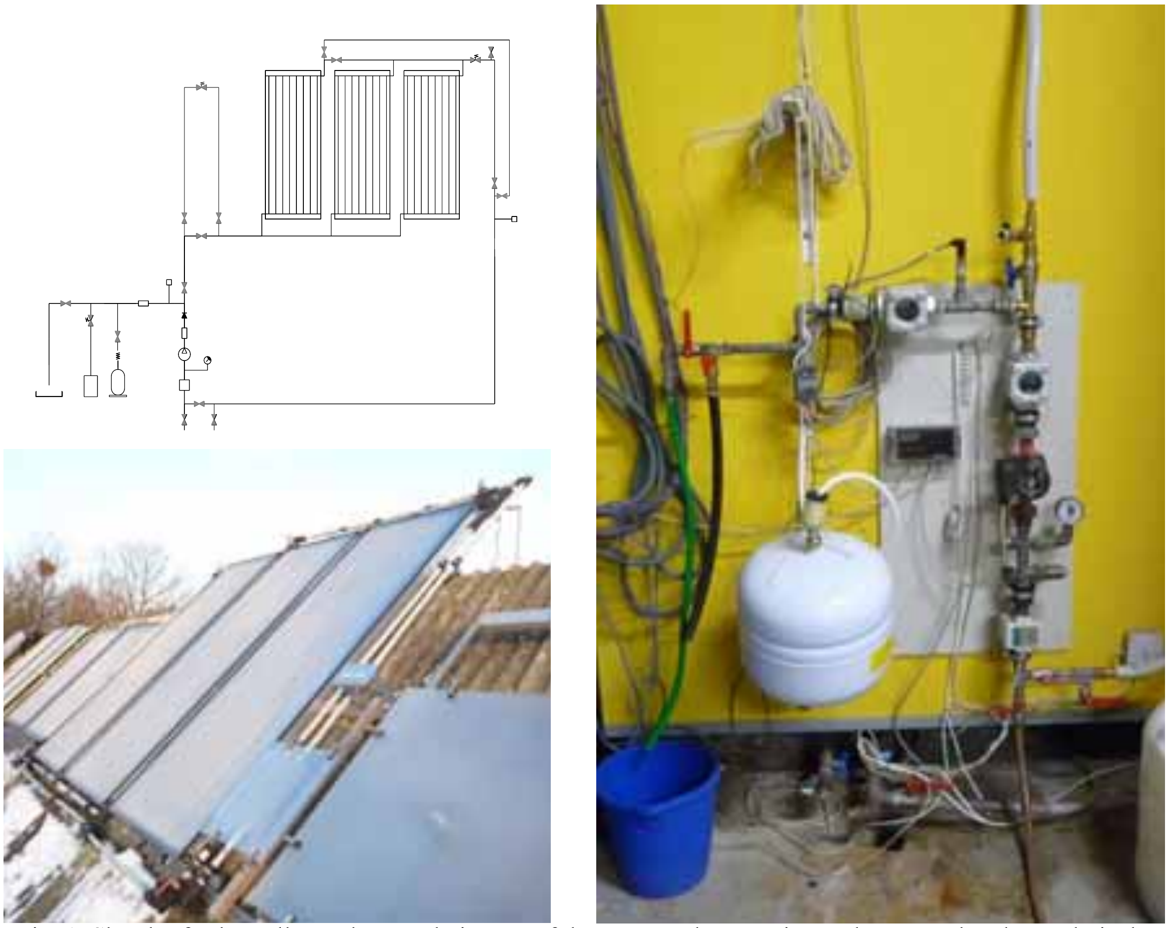

Fig. 1. Sketch of solar collector loop and pictures of the setup at the experimental test stand at the Technical University of Denmark.

The three flat plate solar collectors are BA30 from the Danish company Batec Solvarme A/S, with manifolds at the top and at the bottom and with 8 parallel strips between the manifolds. The collectors have a good emptying behaviour [1], [2]. The transparent area of each collector is 3.00 m². The fluid content of each collector is 2.26 l.

The efficiency expression of the collectors with an incident angle of 0° is:

$$\eta = 0.772 - 2.907 \cdot \left(\frac{t_m - t_a}{G}\right) - 0.015 \cdot \left(\frac{(t_m - t_a)^2}{G}\right) \quad (1)$$

The incidence angle modifier is:

$$k_\theta = 1 - tan^{3,4}\left(\frac{\theta}{2}\right) \quad (2)$$

In the experimental setup the collectors are placed with a tilt of 45° and an orientation of 10° towards west from south.

The pressurized expansion vessel, which is from the company Elbi, has a volume of 24 l and a pre-pressure of 3.0 bar.

The solar collector fluid is a 32% mixture of propylene glycol and water without inhibitors.

## 2.1. Measurements equipment

The measurement period was from 15th July 2009 until the 31st of March 2010, during which measurements were collected both electronically and manually.

The measurements collected electronically: Total and diffuse radiation on the collector surface, pressure in the top and bottom of the solar collector loop, the weight of the expansion vessel and temperature measurements both inside the solar collectors and in the solar collector loop. Manually the PH-value and propylene glycol % of the solar collector fluid was recorded throughout the experiment.

The solar radiation is measured with pyranometers from Kipp and Zonen. The total radiation is measured with a CM 11 and diffuse radiation with a CM 5 pyranometer.

The pressure is measured in the solar collector loop at the level of the bottom of the collectors and at the inlet to the expansion vessel. The pressure is measured with pressure sensors from Sensor Technics. Type CTE8010GQ0.

The expansion vessel is installed in such a way that the increase in weight of the vessel is monitored by a transducer from Celesco.

## 2.2. Setup and measuring period

During the measuring period different setups are investigated, along with variations of the pre-pressure of the expansions vessel and the system filling pressure, to test different conditions for stagnation.

The different setups investigated are: One collector with direct inlet (A), one collector with U-inlet (B), three collectors with direct inlet (C) and three collectors with U-inlet (D), see Fig. 2.

The strategy for the experiment is to control the pump in the collector loop in such a way that it is turned off when the temperatures in the collectors reach 90 °C. This induces stagnation in the collectors.

During the entire measuring period, 97 stagnation periods were registered. The continuous measurements of the PH-value and propylene glycol percentage showed no change in either. PH-value maintained a value of 7 and the propylene glycol percentage stayed at 32%.

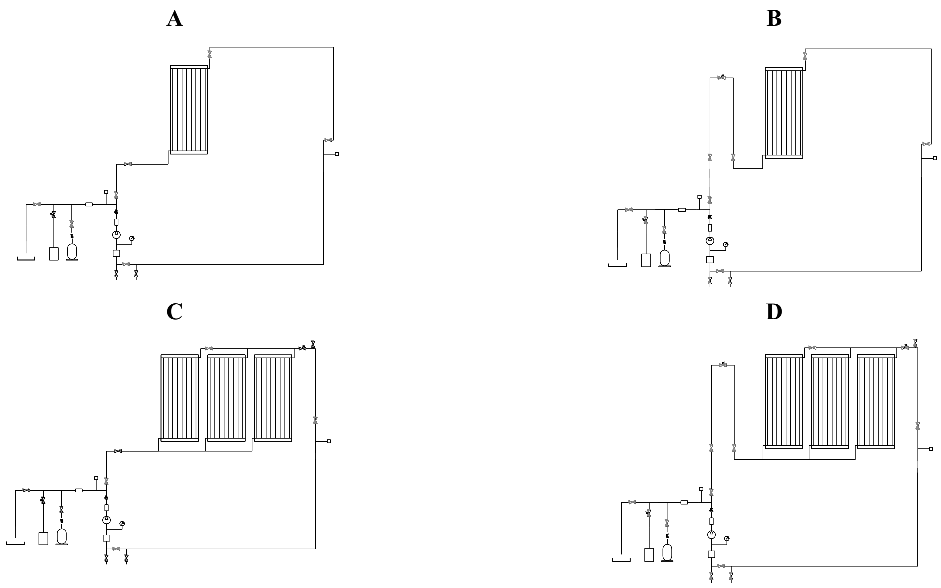

Fig. 2. Sketches of the different setups investigated.

## 2.3. Measurements for a sunny day

September 1st 2009 was a clear day with very few white clouds and high outdoor temperatures, see Fig. 3. The solar collector loop included three solar collectors with direct inlets to the collectors. The pre-pressure of the expansion vessel was 1.0 bar, and the system filling pressure was also 1.05 bar.

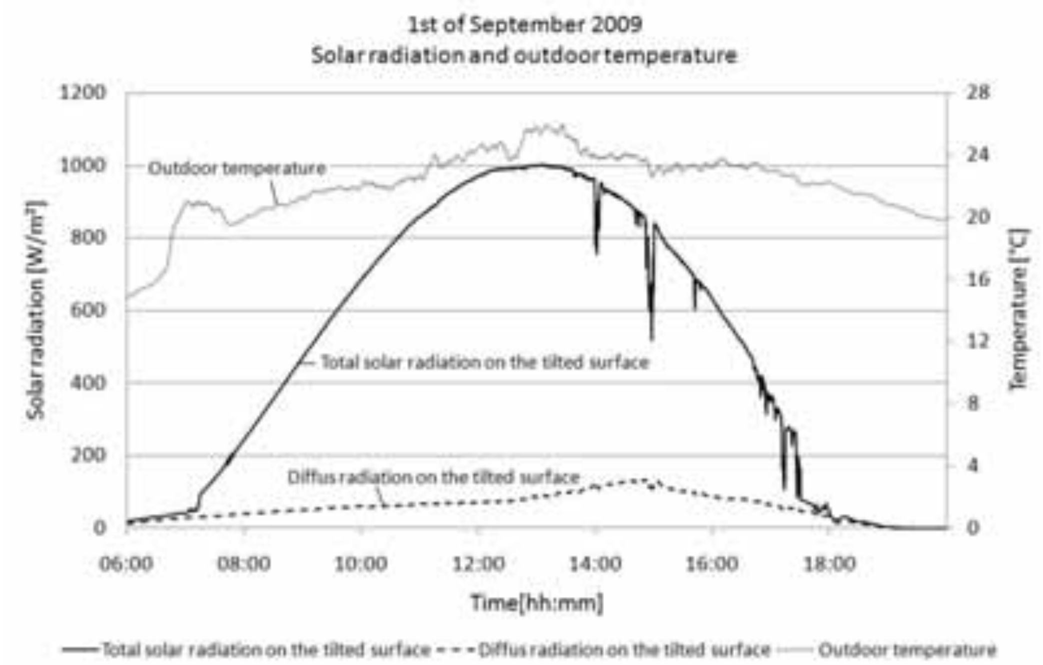

Fig. 3. Solar radiation and outdoor temperature on the 1st of September 2009.

On Fig. 4 the increase in weight of the expansion vessel is shown along with the pressure measured in the system. It can here be seen that the collectors reach stagnation just after 10:00 am, and this state is maintained until the afternoon around 15:30 pm.

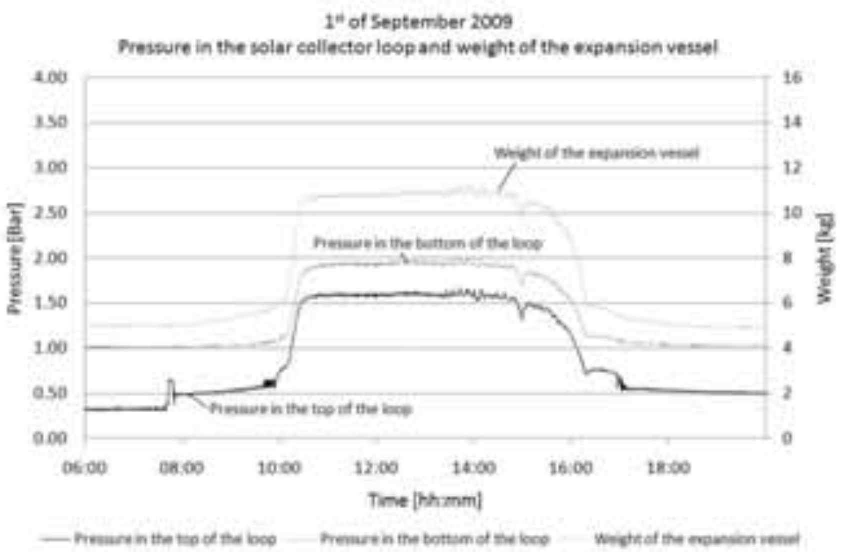


Fig. 4. Pressure in the collector loop and weight of the expansion vessel on the 1st of September 2009.

The weight of the fluid pushed into the expansion vessel can be seen on Fig. 5 along with the pressure difference between the top and the bottom of the collector loop. The figure shows that 6.5 kg is pushed into the expansion vessel during stagnation, which corresponds to 95% of the total fluid volume in the solar collectors.

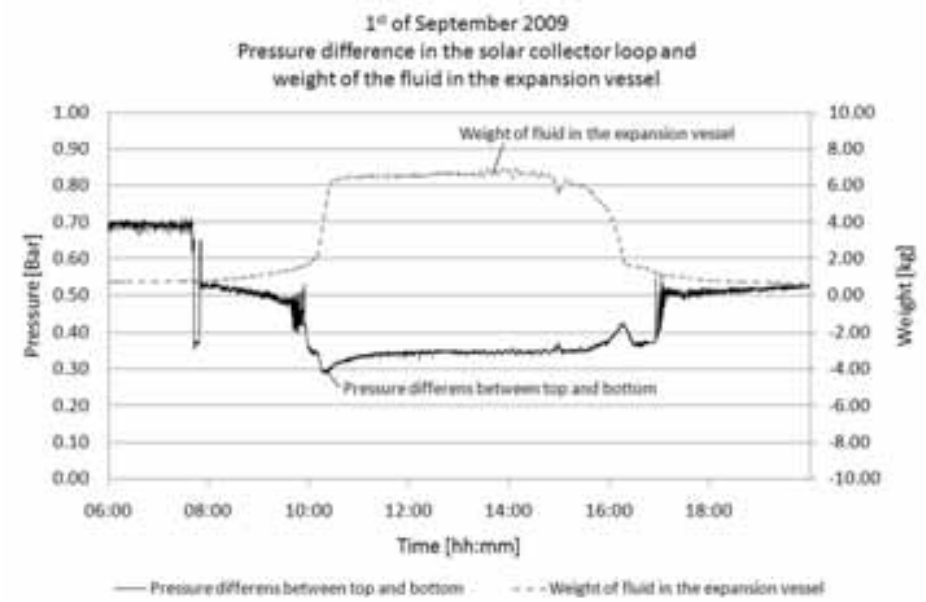


Fig. 5. Weight of fluid in the expansion vessel and pressure difference between top and bottom in the collector loop on the 1st of September 2009.

In the investigations of the other setups, the measurements show that the volume pushed into the expansion vessel during stagnation varies from 90% to 109% of the total volume of fluid in the collectors. When the volume in the expansion vessel exceeds 100%, the steam production in the collectors is pushed into the pipe leading away from the collector through the top outlets of the collectors. The interface between gas and fluid is at the bottom level of the collectors, both in the pipe and in the collectors.

The fluid volume pushed into the expansion vessel during stagnation is also influenced by the pre-pressure of the expansion vessel and the system filling pressure.

Fig. 6 shows the temperatures in the collector loop from the expansion vessel to the inlet to the collectors. As soon as the pump is turned off, high temperatures in the solar collectors are prevented from reaching any vital components of the collector loop. The fluctuation seen close to the inlet of the collectors is due to a continuous change of the level of the interface between gas and fluid in the collectors, resulting in changing fluid flow directions in the inlet pipe to the collectors.

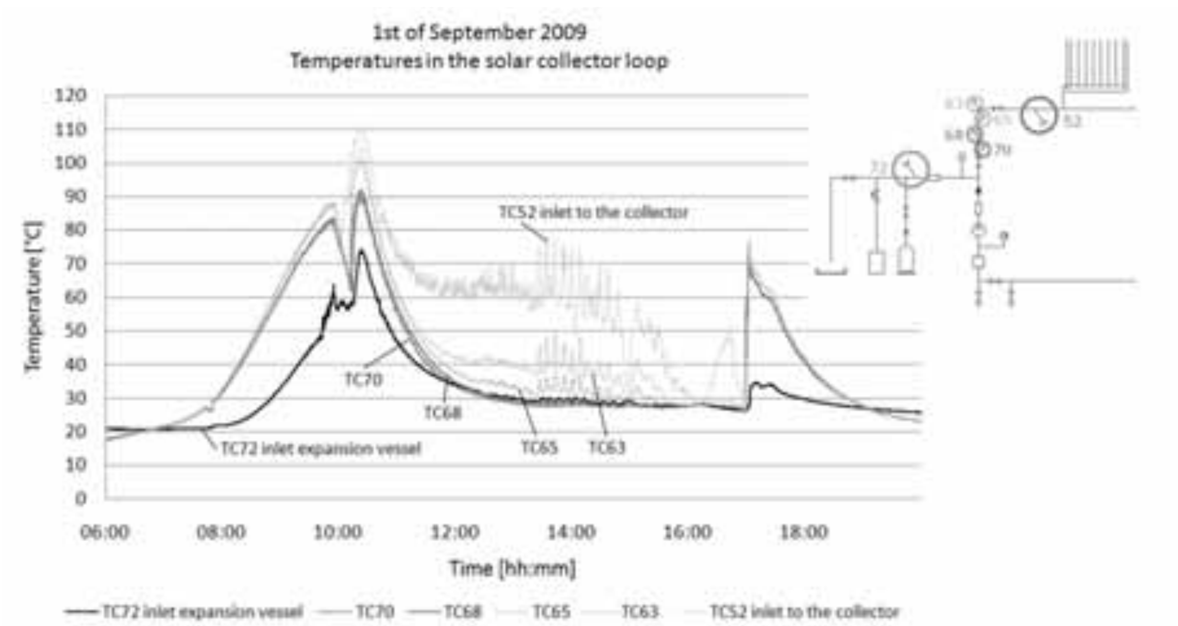


Fig. 6. Temperatures in the collector loop from the expansion vessel to the inlet to the collectors on 1st of September 2009.

The temperatures in the collector loop from the outlet from the collector to the expansion vessel can be seen in Fig. 7. The same tendency can be seen here: as soon as the pump is turned off the transfer of high temperatures is stopped.

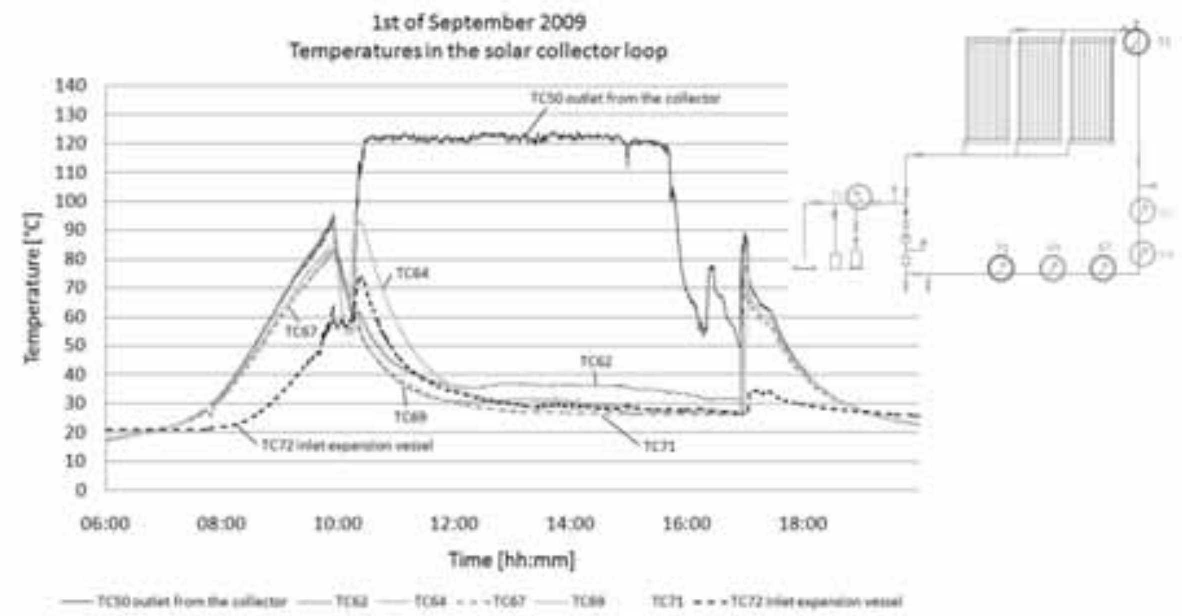

Fig. 7. Temperatures in the collector loop from outlet of the collectors to the expansion vessel on 1st of September 2009.

The investigations with the U-connection before the inlet to the collectors show that this has little effect on the temperature development, pressure, and mass of fluid pushed into the expansion vessel. This means that having a non-ideal connection to the collectors is of no vital importance as long as the solar collectors have good emptying behaviour. Investigations with one solar collector in the solar collector loop give similar results. Consequently the principle with a large expansion vessel and a control system turning the circulation pump off at a high temperature level will result in a durable solar collector loop as long as solar collectors with a good emptying behaviour and a propylene glycol water mixture without inhibitors are used.

## 3. Dimension sheet for installers

The aim of the project was also to provide installers with a dimensioning tool for dimensioning the expansion vessel. This was fulfilled with a detailed investigation of the theory of stagnation and validation of a simulation model by means of measurements, [3]. Based on this an excel-sheet was developed. The input to the excel-sheet are: Number of collectors, fluid content of collectors, inner pipe diameter of the top part of the collector loop, pipe length of the top part of the collector loop, total volume of solar collector fluid in the system, propylene glycol percentage of the solar collector fluid, max. acceptable temperature for the solar collector fluid, vertical distance between the collectors and the expansion vessel, pre-pressure of the expansion vessel and the system filling pressure. On Fig. 8 the volume of the expansion vessel can be determined for a specific system for different pre-pressures of the expansion vessel and system filling pressures.

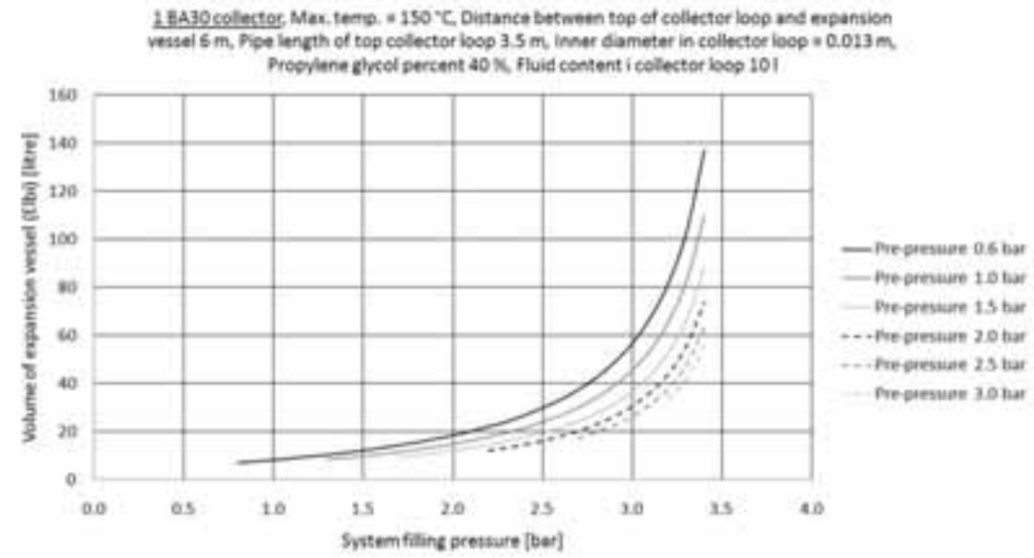


Fig. 8. Example of dimensioning tool for expansion vessel.

## 4. Conclusion

Investigations have shown that during stagnation the solar collector fluid in the solar collectors evaporate and expand. This expansion pushes collector fluid into the inlet pipe and into the expansion vessel. During the stagnation high temperatures are maintained in the collectors, while the temperatures in the solar collector loop are relatively low. This is independent of the different setup with different numbers of collectors and different inlet connections. The volume pushed into the expansion vessel varies from 90% to 109% with the different setups, pre-pressures of the expansion vessel and filling pressures of the system.

During the measuring period 97 stagnation periods were recorded. The solar collector fluid maintained a propylene glycol percentage of 32% during the whole measuring period, and the PH-value of the fluid kept at a value of 7 throughout the period.

The investigations showed that a large pressurized expansion vessel will secure a solar heating system from critically high temperatures as long as the collectors have a good emptying behaviour, a propylene glycol water mixture without additives, and a control system turning off the pump at a high temperature level is used.

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