Development of a Accelerated Performance Check Procedure for Solar Thermal Collectors

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Abstract

The share of automatic productions lines in the manufacturing process of solar thermal collectors is increasing rapidly. Due to this fact, an online procedure to check the quality of the products becomes more and more important.

In order to characterise the thermal performance and the quality of solar thermal collectors, testing of these products is required. The assessment of a solar thermal collector requires reliable and universally valid test procedures as the ones documented in the corresponding European standard EN 12975.

The disadvantages of such reliable and well established test procedures are the significant cost-intensive infrastructure and manpower, which is needed for performing these time-consuming tests in a standardized way. For these economic reasons the standardized test procedures are not suited for continuous production control.

To overcome this problem Solar- und Wärmetechnik Stuttgart (SWT) developed a accelerated test procedure, in cooperation with the Institute for Thermodynamics and Thermal Engineering (ITW). This procedure, named QuickSol, is based on the comparison of different *pressure time curves* of a reference collector determined according to the corresponding standard (e.g. EN 12975-2 thermal performance [1]) to the collector to be tested.

The different pressure time curves are gained by using a low cost solar simulator, which can be part of the production line or located adjacent to it. This comparison enables the detection of a reduced thermal performance very easily. So, typical production failures such as non-conforming selective coating, bad thermal insulation, or reduced transmission of the transparent cover can be detected quickly.

The present paper describes the thermodynamic background and the preparatory examination of the developed accelerated performance check procedure. Further the test facility installed for this procedure is characterized and finally the accomplished validation of the accelerated performance check procedure is substantiated with power curves of different modified collectors determined according to EN 12975.

1. Thermodynamic Background

The density of almost all materials depends on the temperature of the material itself. This applies mainly for the gas phase, but also for liquids and solids. Out of this temperature dependency a pressure increase is resulting for a gas or liquid under the condition of a heat supply into a closed volume (isochoric change of state).

Two materials for filling the collector were considered for performing the Quicksol test procedure: water and air. The advantages of both materials are ready availability and the handling.

Due to theoretical considerations, air was finally chosen as the working fluid for filling the collectors. The main reason was the lower specific heat capacity of air. Using water would result in a considerable longer period for heating up the collectors. Additionally water is almost incompressible. This characteristic will cause an enormous pressure increase even if only a small amount of heat is supplied and hence the collector to be tested may be damaged. Calculations have shown that by using air as working fluid the final pressure during stagnation conditions of a typical flat plate collector under an irradiance of 500 W/m² is in the range of 180 mbar above the initial ambient pressure of 1 bar. With regard to security aspects the use of compressed gas in this temperature and pressure range is straight forward and safely manageable. A further advantage of using air is the simple “filling” and “emptying” of the collectors. Additionally there is no risk for corrosion.

The major drawback of using air is the fact that the collector needs to be completely dry. Remaining water inside the collector would evaporate during the test and thus lead to a higher pressure increase.

2. Concept of the test facility

For realising an integration of the accelerated test procedure into an automatic production line, the test facility needs to be small and easy to handle. The base area is only marginally larger than the one of a conventional flat plate collector. Since the test procedure is a comparative procedure, the solar simulator’s spectrum does not need to meet the sunlight’s spectrum. Therefore, conventional 250 W light bulbs can be used. Furthermore a so-called cold sky that avoids penetration of the collector with long wave heat radiation from the bulbs is not necessary.

Figure 1: First version of the test facility

The only important requirement for the solar simulator is a relative homogenous radiation over the entire test area with an intensity of 500 W/m² to 600 W/m².

A first demonstrator of the test facility including a low-cost solar simulator with 15 light bulbs was set-up as shown in figure 1.

3. Preparatory examination

For validation of the test procedure two collector type series have been used. Both type series, one with flat plate and one with vacuum tube collectors with CPC reflector; consist of five identical collectors each. Out of each type series one collector remained unchanged, the other four collectors have been modified in different ways in order to simulate characteristic production failures. The modifications realized are listed in table 1.

Table 1: Modifications of both collector type series

Modification	**Flat plate collector series**	**Vacuum tube collector with CPC reflector series**
Reference	- (non modified)	- (non modified)
1	Decreased absorption (partly masking of the absorber with aluminium foil)	Increased heat losses (destroying of the vacuum of one tube)
2	Increased the heat losses (removal of the thermal insulation)	Decreased heat flux between absorber and heat transfer fluid (removal of the heat transfer sheet)
3	Increased emissivity (painting of the absorber with black colour)	Decreased transmissivity of the transparent cover (partly masking of the tubes with white paint)
4	Decreased transmissivity of the transparent cover (partly masking of the cover with white paint)	Decreased reflecting area (partly masking of the reflector)

4. Efficiency measurements

All collectors of both collector type series have been tested according to EN 12975 using a high-end solar simulator of the Institute of Thermodynamics and Thermal Engineering (ITW) at the University of Stuttgart. By this test for the reference collectors as well as for the modified collectors the corresponding efficiency curves were determined. The efficiency curves for the reference and two exemplary modified collectors of both type series are shown in figures 2 and 3.

For the flat plate collector type series the modifications 2 and 3, for the evacuated tube collector with CPC-reflector the modifications 1 and 2 have been selected. The efficiency curves of the modified collectors reflect the realized modifications and therefore are below the curves of the corresponding reference collector.

The efficiency curves determined for the various collectors will be used for the validation of the accelerated test procedure.

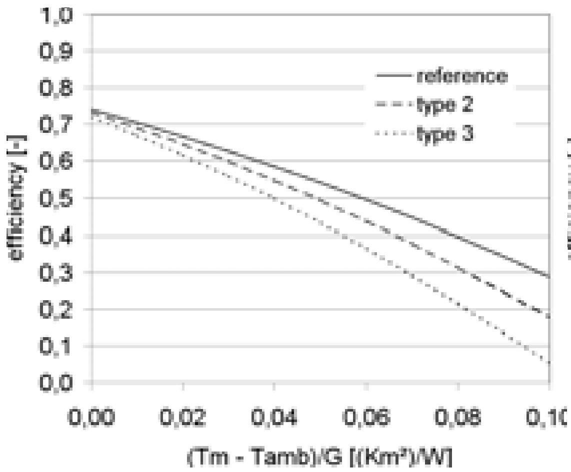

Figure 2: Efficiency curves of the reference and two modified flat plate collectors

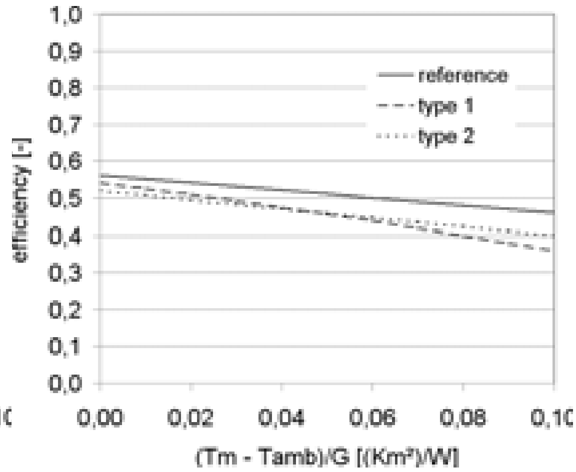

Figure 3: Efficiency curve of the reference and two modified vacuum tube collectors

5. Development of the accelerated test procedure

At first the non-modified collectors have been exposed to the artificial radiation in the test facility demonstrator and the pressure difference between the collector and the ambient has been recorded over the time. Afterwards the modified collectors were tested in the same way and the pressure difference time curves were recorded as well and compared to the curves of the reference collectors. The corresponding curves are shown in figures 4 and 5.

It is obvious that the pressure difference time curves of the modified collectors are below the ones of the non-modified collector, as this is also the case for the efficiency curves (see figures 2 and 3).

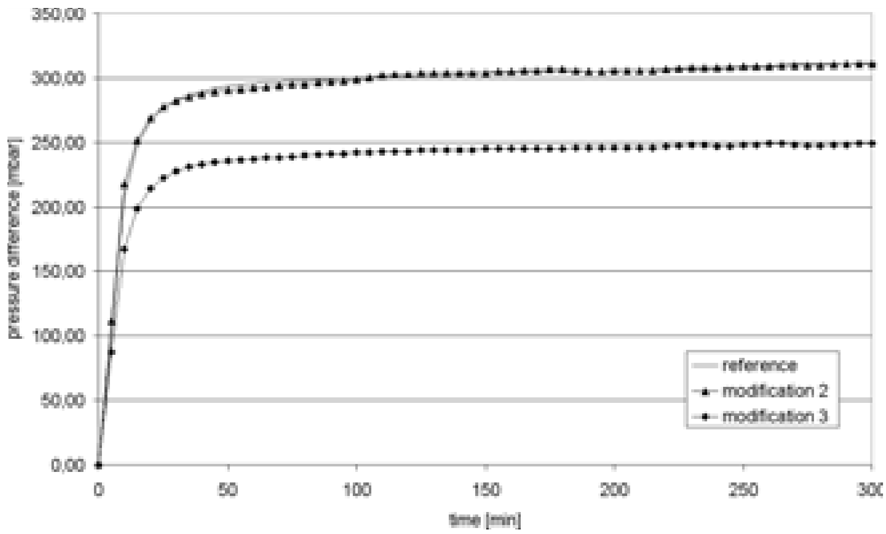

Figure 4: Pressure difference vs. time curves for three out of five flat plate colectors

The curve of the **flat plate collector**, whose modification was the increased emissivity (modification 3), shows the highest deviation from the reference collector's efficiency curve (see also figure 2) as well as from the reference collector's pressure difference time curve (figure 4).

Concerning the increased heat losses (modification 2), the measured pressure difference time curve is by far higher than expected and therefore considerably closer to the curve of the reference collector. This result was not expected and led to several further investigations. As a result the geometrical lay-out of the collector to be tested was detected as the main reason: The collectors have been tested laying horizontally in the facility. Thus the influence of the missing insulation on the backside of the collector is minimized since natural convection cannot develop as intensely as it is the case of a collector installed with a certain inclination.

Referring to the **vacuum tube collectors**, the pressure difference vs. time curve of the collector, whose modification was the increase of the thermal losses (modification 1), shows also reasonable characteristics. For rising values of the collector temperature the thermal losses are also increasing (figure 3). The same characteristic is identifiable in figure 5 where the deviation between the pressure difference curves of the modified and the reference collector is also increasing over the test duration or the temperature level, respectively.

The pressure difference vs. time curve of the collector with the increased heat losses (modification 1) is always below the curve of the reference collector. Compared to that, the curve of the collector with the removed heat transfer sheet shows a different characteristic: During the initial heating period the pressure difference rises quicker for the collector without heat transfer sheet than the pressure difference of the reference collector, due to the decreased heat capacity. Towards the stagnation period, however, the pressure difference for the collector without heat transfer sheet stays below the one of the reference collector because of the less favourable connection of the absorber to the heat transfer fluid.

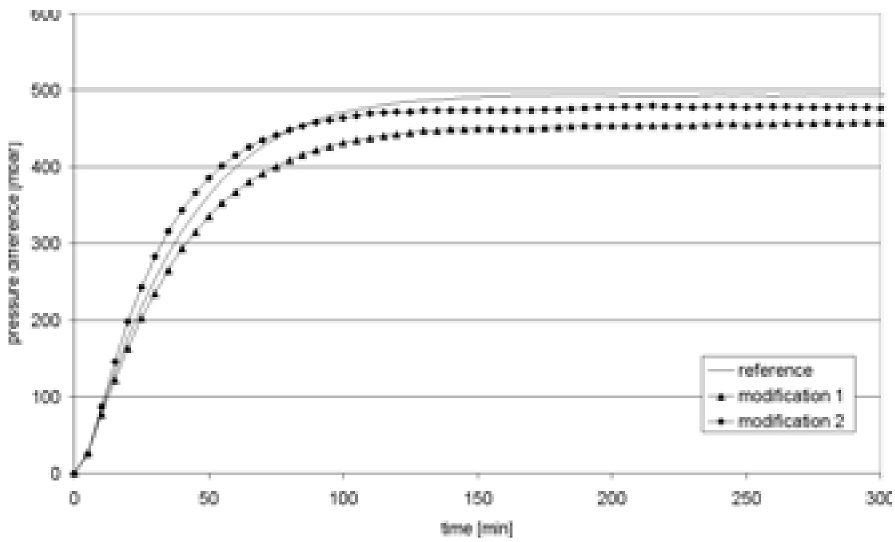

Figure 5: Pressure difference vs. time curves of three out of five evacuated tube collectors

These results of the first measuring and validation campaign of the accelerated test procedure, which are described in more detail in [2], made it necessary to re-design and re-construct the test facility. The new demonstrator is shown in figure 6.

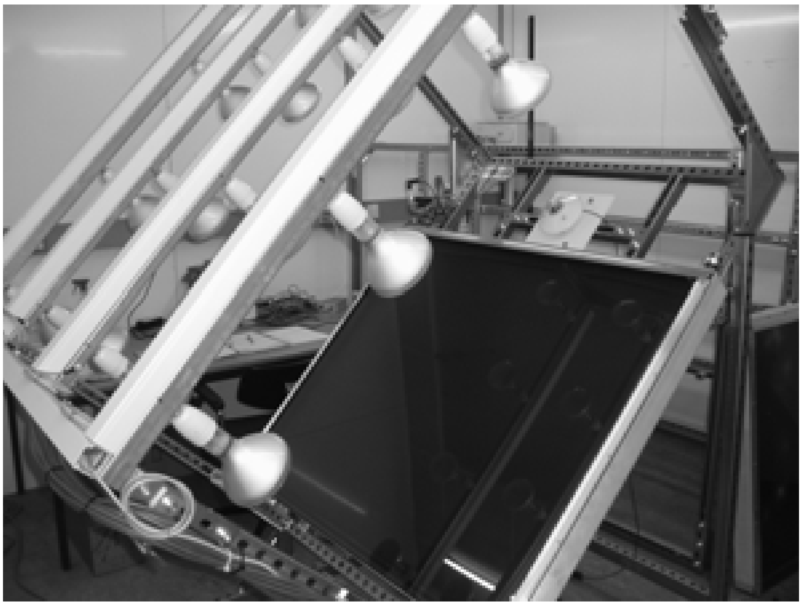

Figure 6: Second version of the test facility

Main reason for reconstructing the test facility was the missing inclination of the test surface. The tilt angle of 45° reproduces the correct physical processes related to thermal losses (mainly thermal losses by natural convection). Therefore, by testing in the reconstructed facility, the modified flat plate collector with the removed insulation on the backside did achieve a result, which is representative for this failure.

Additionally, re-arranging the individual light bulbs increased the homogeneity of the lamp field.

Furthermore, a device allowing for a higher initial pressure within the collector was developed. A higher initial pressure will result in higher pressure differences during the measurements which results in considerably clearer signals and more reliable results. This is due to the thermodynamic processes related to the gas phase. Assuming the air inside the collector is an ideal gas, the following relationship will apply for isochoric processes:

$$p_2 = p_1 \cdot \left(\frac{T_2}{T_1} \right) \quad (1)$$

From this it follows that the final pressure p_2 is linearly dependent on the initial pressure p_1. Increasing the initial pressure will therefore cause a considerable increase in measured pressure difference and hence improve the reliability of the results.

As last modification an absolute pressure sensor was installed instead of a pressure difference sensor. The reason for this change was the extended measuring range due to the higher initial pressure. The sensor used so far did not entirely cover the new pressure range.

6. Validation of the accelerated test procedure

For validation of the accelerated test procedure and the conclusions found by the previous investigations, a third collector type series consisting of five flat plate collectors was selected. Again four of these five collectors have been modified. In table 2 the realized modifications are listed.

Table 2: Modifications of the third collector type series

Modification	Flat plate collector series
Reference	- (non modified)
1	Decreased absorption (partly painting of the absorber with white colour)
2	Increased heat losses (removal of the thermal insulation)
3	Increased emissivity (painting of the absorber with black colour)
4	Decreased transmissivity of the transparent cover (replacing of the transparent cover bya conventional glass sheet)

Due to the new measuring device for the absolute pressure, no pressure difference time curves could be generated. Therefore, the comparison of the five collectors tested is shown by means of the collector temperature versus time (see figure 7). The collector temperature T_2 was calculated by using equation 1, with the initial conditions of $T_1 = x$ and the pressure difference (p_2 - p_1); where p_1 = 2,5 bar and p_2 represents the measured pressure inside the collector.

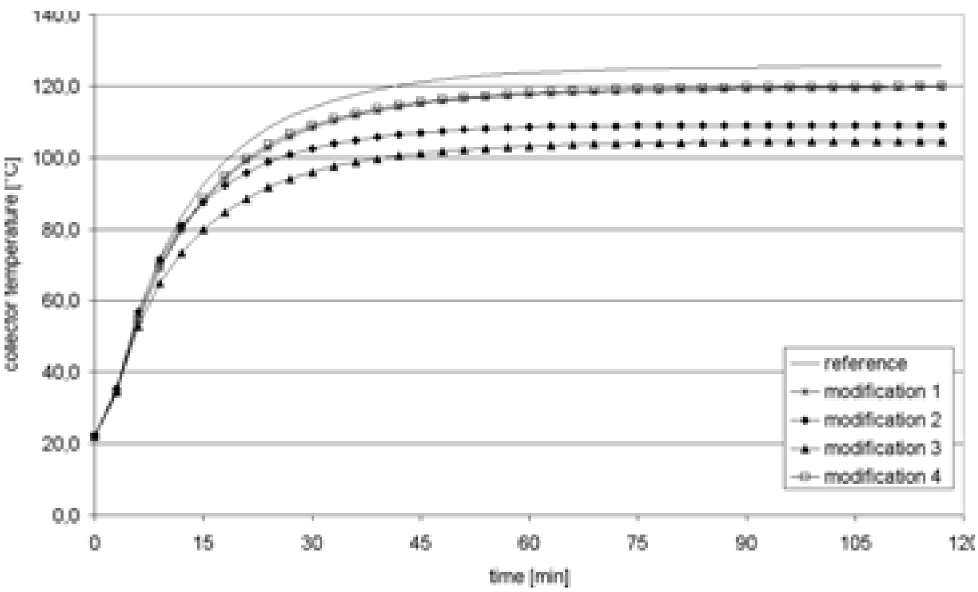

Figure 7: Temperature time curves for all five flat plate collectors (3rd type series)

The measurements shown in figure 7 were performed with an initial pressure of 2.5 bar. The temperature vs. time curve of the reference collector reaches the highest temperature, i.e. all modifications lead to a decrease of the stagnation temperature of the collectors. The curves of collector modification 1 (lower absorption) and modification 4 (lower transmissivity) show almost the same characteristic and therefore lead to the same stagnation temperature. Hence, it is generally not possible to determine which failures or combinations of several failures are the reasons for a lower curve.

The increase of the emissivity (modification 3) does have the strongest influence on the temperature vs. time curve. In the present case, this failure causes a lower stagnation temperature by about 20 K.

The increase of the heat losses (modification 2) has also considerable influence on the temperature vs. time curve, leading to a lower stagnation temperature by about 15 K.

7. Conclusions

The suggested accelerated performance check procedure in combination with the optimised demonstrator test facility is suitable for performing comparative measurements of the thermal performance of solar collectors during the production process.

Using the accelerated performance check procedure, the following shall be considered:

- The primary pressure should be at least at 2.5 bar.
- The irradiation should be kept constant.
- The ambient temperature should be kept constant.
- The collector to be tested should not contain any water.
- The collector should be inclined by 45 ° ±10 °.

To obtain reliable results of the thermal performance a test duration of 30 to 60 minutes is required.

Due to the test duration of 30 to 60 minutes this accelerated test procedure is no t yet suitable for continuously testing all produced collectors; it is rather suitable for testing of randomly selected samples.

The pressure vs. time characteristics are basically dependent on the conversion factor η_0 and the thermal losses. The specific collector values of the performance test according to EN 12975 cannot be determined from the pressure vs. time curves with exception of the effective collector heat capacity.

For determining reliable results comparable to collectors tested according to EN 12975-2, the lamps of the solar simulator used for the accelerated test procedure must be adjusted to the spectral characteristics of the absorption-transmission product of the collector to be tested.

The developed accelerated performance check procedure is an excellent tool for integration into large scale collector production processes as an enhanced quality assurance measure. It is, therefore, intended to develop a market ready product based on the results described above.

References

[1]EN 12975:2006, Thermal solar systems and components – Solar Collectors, June 2006.
[2]OTTI - 20. Symposium Thermische Solarenergie 05.05. - 07.05.2010

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