Test Procedure for Accelerating Aging of Solar Thermal Collectors

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Abstract

Based on the experience and data gained during a 3 year exposure of different solar thermal collectors under different climate conditions (tropical, arid, arid maritime, moderate and cold alpine) and system simulations using TRNSYS a test procedure for accelerating aging of solar thermal collectors has been developed and exemplary conducted on flat plate collectors. The overall test procedure which comprises a UV resistance test, a salt mist test, a humidity test, a temperature cycle test and an extended high temperature test is introduced and described in detail.

Key-words: collector test, accelerated aging test, lifetime prediction

1. Introduction

During their lifetime solar thermal collectors are exposed to a variety of partially overlapping aging effects. These are introduced on the one hand from the system type and the mode of operation resulting in different inlet temperatures of the heat transfer fluid. On the other hand site-specific climatic conditions have an important impact on the aging process as shown by B. Traub et al. (2012) and P. Kofler et al. (2013).

To assess and judge the durability and reliability of solar thermal collectors for different system types and different locations a test procedure which takes into account these different ageing processes is needed which goes far beyond the existing durability and reliability test sequences which are documented in the ISO 9806 (2013) testing standard. Thus a test sequence was developed within the German project *Speed*Coll taking into account all relevant kinds of different ageing processes a solar thermal collector is exposed during its lifetime. The test sequence comprises the following tests:

- Initial test
- UV resistance test
- Salt mist test
- Humidity test
- Temperature cycle test
- Extended high temperature test
- Final assessment

The test conditions of each single test can be chosen according to the desired climate and system type the collector will be used for. The different test conditions were derived from a three year long outdoor exposure and monitoring at 6 different test sites (Stuttgart (Germany), Freiburg (Germany), Zugspitze (Germany), Gran Canaria (Spain), Sede Boker (Israel) and Cochi (India)) and from the results of simulations using TRNSYS. Table 1 shows the different climates of the exposure sites.

The data monitored included besides the weather data also the measurement of different temperatures within the collectors as the absorber temperature and the temperature with in the glue joint between the glass cover and the frame and the humidity in the collector between the absorber and the glass cover. The resistance of the tested collectors against the single tests is rated by different criteria. These criteria include lasting and the function of the collector or single components influencing changes and include incidences like brakeage of the glass cover or frame, fogging and a reduction of thermal performance.

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Tab. 1: Climates and exposure sites

Climate	Exposure site	Remarks
Tropical climate	Cochi (India)	Hot, humid and wet (Monsun) conditions
Arid climate	Sede Boqer (Israel)	Hot, dry and sandy
Arid maritime climate	Gran Canaria (Spain)	Saline atmosphere
Moderate climate	Stuttgart (Germany)	-
Moderate climate	Freiburg (Germany)	-
Cold alpine climate	Zugspitze (Germany)	High mechanical load through wind and snow loads

2. Initial test

Before the collector will go through the actual aging tests the following initial tests will be carried out

1. Thermal performance test according to ISO 9806, section 20 "Performance testing of fluid heating collectors" to assess the thermal performance prior to aging testing.
2. Mechanical load tests according to ISO 9806, section 16 "Mechanical load test with positive or negative pressure" with a load (positive and negative) of 2400 Pa to ensure a minimum resistance against wind and snow loads. The load (positive and negative) of 2400 Pa is applied 10 times.

3. UV resistance test

To pre-age the collector and to assess the ability of the collector construction including collector parts as polymeric sealing, transparent covers, adhesives and other potential parts sensitive to ultraviolet (UV) radiation the collector is tested using an artificial UV source.

The test setup consists of a climate chamber, light sources and instrumentation with the following specifications:

- Maximum UV radiation (280 nm – 400 nm) shall not exceed 230 W/m² at any location in the collector plane
- The homogeneity of the UV-radiation shall be in the range of ± 15 %. Homogeneity shall be measured at least at 6 locations, evenly distributed over the collector plane.
- Relative humidity in the climate chamber shall be in the range of 15 % ± 5 %
- The temperature in the climate chamber shall be controlled to a value which results in a surface temperature of the collector frame of 80 °C ± 2 °C, measured at location of frame at the top of the collector in an area which is not directly irradiated.
- All temperatures are measured with a standard uncertainty of ± 1 K.

The collector is placed in the climate chamber at a tilt angle of at least 60° and parallel to the light source. The light source is turned on and the climate chamber is set to 15 % relative humidity. Afterwards the temperature within the climate chamber is adjusted such that the surface temperature of at the location of the collector frame at the top of the collector in an area which is not directly irradiated reaches 80 °C ± 2 °C. When this temperature is reached the test begins. During the test ambient temperature, frame temperature and UV irradiance (280 nm – 400 nm) is measured and recorded. The test is completed after an UV irradiation of 280 kWh/m² is reached.

After the test the collector is visually examined and obvious changes or damages like decolouring, changes in structure or surface are documented.

4. Salt mist test

Collectors are often installed close to the sea side and are exposed to significant loads of salt in the air. The test is intended to assess if and to what extend salt will enter the collector and deposit on the absorber and other parts of the collector.

The test setup consists of a salt mist chamber according to EN 60068-2-52:1996 (EN 1996), section 4. A natrium chloride (NaCl) solution of 3 % ± 0.5 % is used. The pH-value of the solution is in the range of 6.5 to 7.2. The salt mist chamber is qualified for the measurement using working standards according to EN ISO 9227:2012 (EN 2012). The working standard is placed in the salt mist chamber at a tilt angle of 70° and is exposed for 48 h a salt mist spray at an ambient temperature of 35 °C ± 2 °C and a relative humidity of more than 90 %. The removal of the working standard shall be 85 g/m² ± 20 g/m²after the test. A pumped heat transfer loop using a suitable heat transfer liquid, with the collector forming part of the loop.

The collector is placed in the salt mist chamber at a tilt angle between 30° and 60° and connected to the heat transfer loop. Afterwards the test cycle as shown in Table 2 is performed on the collector.

During the test the relative humidity and the temperature with in the salt mist chamber shall be measured and recorded. The test is completed when altogether 22 cycles (see Table 2 and Figure 1 are completed.

Tab. 2: Test cycle salt mist test

Phase (duration)	Description
Humid phase (5 h)	Heat transfer loop on, mean heat transfer fluid temperature ϑ_m = 60 °C ± 2 °C. Ambient temperature with in the salt mist chamber ϑ_a = 40 °C ± 2 °C. Relative humidity φ > 90 %
Salt mist phase (2 h)	Heat transfer loop on, mean heat transfer fluid temperature ϑ_m = 60 °C ± 2 °C. Ambient temperature with in the salt mist chamber ϑ_a = 35 °C ± 2 °C. Relative humidity φ > 90 %
Humid phase (10 h)	Heat transfer loop off, ambient temperature with in the salt mist chamber ϑ_a = 40 °C ± 2 °C. Relative humidity φ > 90 %
Salt mist phase (2 h)	Heat transfer loop off, ambient temperature with in the salt mist chamber ϑ_a = 35 °C ± 2 °C. Relative humidity φ > 90 %
Humid phase (5 h)	Heat transfer loop off, ambient temperature with in the salt mist chamber ϑ_a = 40 °C ± 2 °C. Relative humidity φ > 90 %
Drying phase (24 h)	Heat transfer loop on, mean heat transfer fluid temperature ϑ_m = 60 °C ± 2 °C. Ambient temperature with in the salt mist chamber ϑ_a = 23 °C ± 2 °C. Relative humidity in the range of 30 < φ < 70 %

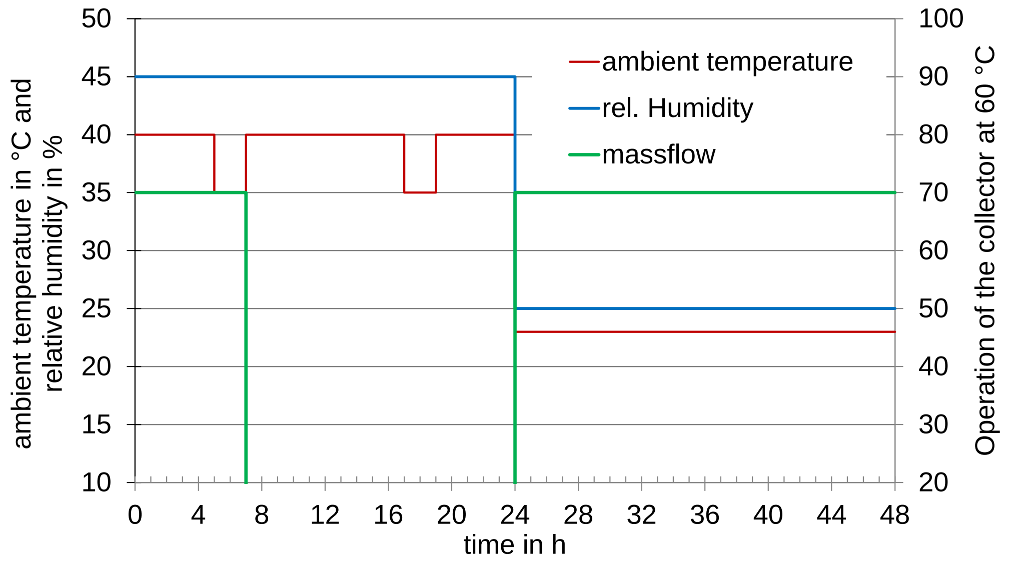

Fig. 1: Schematic test cycle salt mist test

5. Humidity test

The humidity test is designed to test the durability of the collectors against high humidity and is realized by the accelerated simulation of the day night cycle within a climate chamber. Figure 2 shows the graphs of temperature and relative humidity within the climate chamber as well as the switching points for turning on and off of the irradiance and the mass flow. Figure 3 shows the resulting graphs of the temperature and the relative and absolute humidity within the air gap between the absorber and glass cover of a tested collector. The graphs during the humidity test are very close to the data recorded during the real exposure as shown by Fischer et al. (2016).

This test cycle accelerates the outdoor exposure by the factor of 4. The boundary conditions like ambient temperature relative humidity as well as the hemispherical irradiance can be adjusted when required.

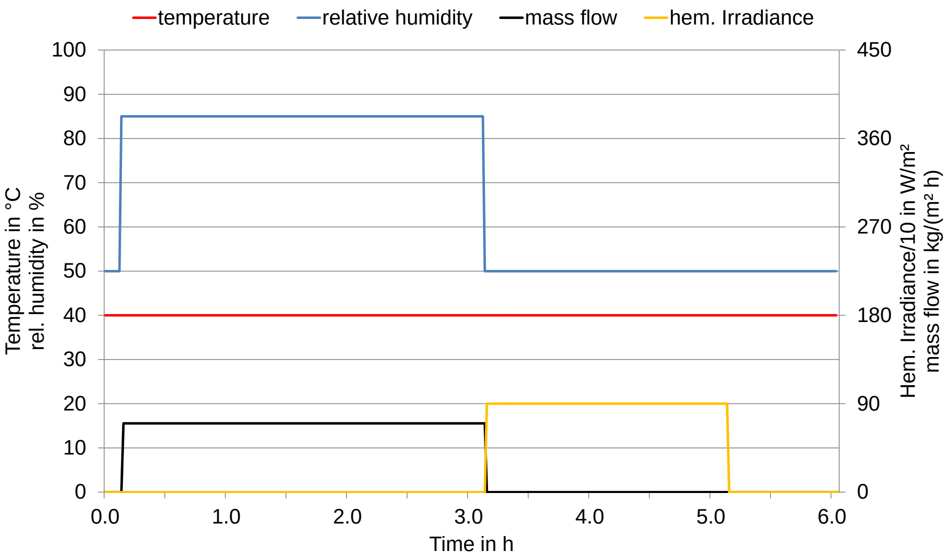

Fig. 2: Temperature, relative humidity, hemispherical irradiance and mass flow during the humidity test cycle

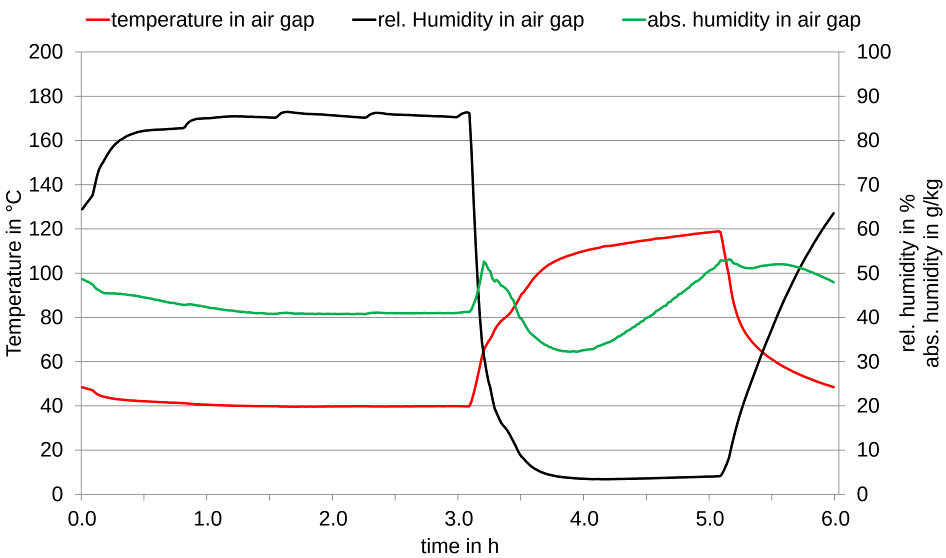

Fig. 3: Temperature, relative and absolute humidity within the air gap between absorber and glass cover of a tested collector during the humidity test

6. Temperature cycle test

During operation a collector and its components will undergo numerous temperature cycles during its lifetime. This test is intended to assess the ability of the collector design to withstand these temperature cycles without damage.

The test setup consists of a climate chamber and instrumentation with the following specifications:

- A climate chamber suitable for the operation in the range of -45 °C to + 95 °C
- The temperature in the climate chamber at quasi-stationary conditions is controlled to a value which results in a surface temperature of -40 °C ± 2 °C and +90 °C ± 2 °C respectively at the top of frame of the collector.
- Instrumentation for the measurement of the relative humidity.
- All temperatures are measured with a standard uncertainty of ± 1 K.

The collector is placed in the climate chamber at ambient conditions (room temperature and corresponding relative humidity). The air in the climate chamber is cooled down to a temperature leading to a temperature at the surface of the frame at the top of the collector of -40 °C ± 2 °C and held at this temperature for 1 h. Afterwards the climate chamber is set to a temperature leading to a temperature at the surface of the frame at the top of the collector reaches +90 °C ± 2 °C and held for 1 h, see Figure 4. During the whole test the temperature and relative humidity within the climate chamber as well as the frame temperature at the top of the collector are measured and recorded. The test is completed when altogether 200 temperature cycles are completed.

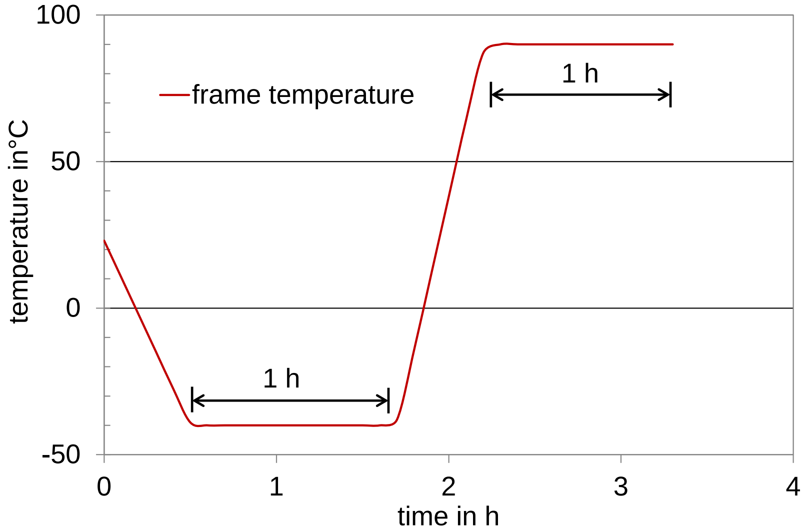

Fig. 4: Schematic test cycle of temperature cycle test

7. Extended high temperature test

This test assesses the ability of the collector to withstand high temperatures during operation and lifetime like they may occur during times with high solar irradiance and high ambient temperature while no heat is removed by circulating the heat transfer fluid (stagnation). Times when the collector needs to withstand these high temperatures are:

- When empty during installation.
- When empty during any period of maintenance.
- When filled with heat transfer fluid or steam at stagnation conditions.

The absorber temperature ϑ_{abs} used for the test is the absorber temperature which will be reached at hemispherical radiation G of 1100 W/m² and an ambient temperature ϑ_a of 50 °C and shall be calculated according to the following equation (1)

$$\vartheta_{abs} = 50°C + \frac{-a_1 + \left(a_1^2 + 4\eta_0 a_2 1100W/m^2\right)^{0.5}}{2a_2} + 20°C \quad \text{(eq. 1)}$$

The collector parameters η_0, a_1 and a_2 are taken from thermal performance measurement during the initial test.

7.1 Method 1: Test setup, conditions and procedure

The test setup of Method 1 consists of a climate chamber, solar simulator and instrumentation with the following specifications:

- A combination of climate chamber and solar simulator which allows to heat the absorber to the required test temperature ϑ_{abs} and to keep this temperature constant to ± 2 K. The irradiance level in the collector plane shall be between 900 W/m² and 1200 W/m².
- A temperature sensor to measure the absorber temperature ϑ_{abs} is positioned at two-thirds of the absorber height and half the absorber width. It is fixed firmly in a position to ensure good thermal contact with the absorber. The sensor shall be shielded from solar radiation.
- A temperature sensor is positioned on the frame at the top of the collector. The sensor shall be shielded from solar radiation.
- Instrumentation for the measurement of the relative humidity.
- All temperatures shall be measured with a standard uncertainty of ± 1 K.

The collector is placed in the climate chamber at a tilt angle of at least 60° and parallel to the solar simulator. All but one of the fluid pipes are sealed to prevent cooling by natural circulation of air. The climate chamber is set to 50 % relative humidity. Solar simulator and climate chamber are set to an irradiance and temperature that the absorber temperature according to equation 1 ± 2 °C is reached. At this stage the test begins and runs for 8 h. Afterwards the solar simulator is shut down and the ambient temperature is set to 25 °C. After 4 h the solar simulator and climate chamber are turned on again until the absorber temperature has stayed another 8 hour time period at the test temperature ± 2 °C. The collector should be visually inspected daily during the cooling phase and any it´s appearance shall be reported. During the whole test the relative humidity and the temperatures of the absorber, the collector frame and of the ambient are measured and recorded. The test is completed when altogether 15 temperature cycles (see Figure 3) are completed.

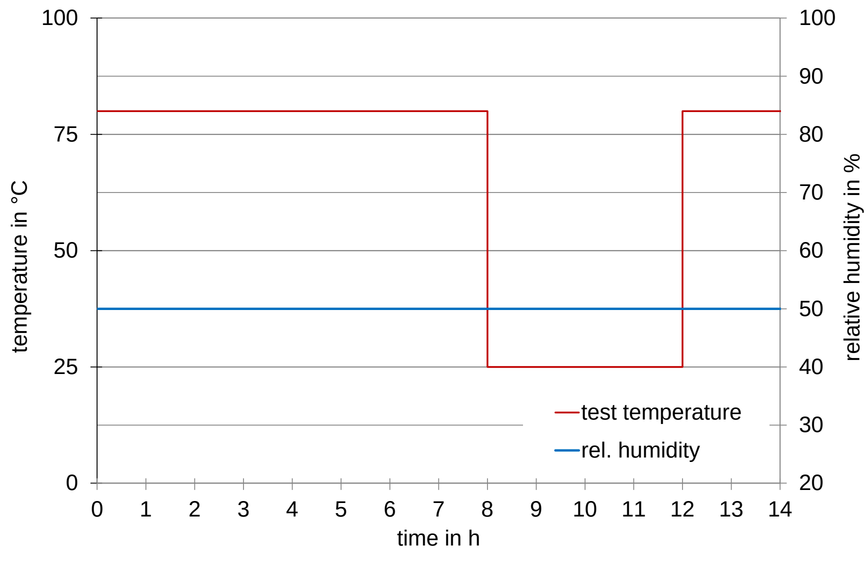

Fig. 5: Schematic test cycle of extended high temperature test

7.2 Method 2: Test setup, conditions and procedure

- A pumped heat transfer loop using a suitable heat transfer liquid, with the collector being part of the loop. A suitable heat transfer fluid is one that will remain in its liquid state at the test temperature and the maximum operating pressure of the collector.
- A temperature sensor to measure the absorber temperature ϑ_{abs} is positioned at two-thirds of the absorber height and half the absorber width. It is fixed firmly to ensure good thermal contact with the absorber. The sensor is shielded from solar radiation.
- A temperature sensor is positioned on the frame at the top of the collector. The sensor shall be shielded from solar radiation.
- Instrumentation for the measurement of the relative humidity.
- All temperatures shall be measured with a standard uncertainty of ± 1 K.

The collector is mounted at a tilt angle of at least 60° and connected to the heat transfer loop. The climate chamber is set to 50 % relative humidity. Heat transfer loop and climate chamber are set to temperatures that the absorber temperature according to equation 1 ± 2 °C is reached. The mass flow rate shall be adjusted in a way that the heat transfer fluid will not lose more than 2 K while passing through the collector. At this stage the test begins and runs for 8 h. Afterwards the heat transfer loop is shut down and the ambient temperature is set to 25 °C. After 4 h the heat transfer loop and climate chamber are turned on again until the absorber temperature has stayed another 8 hour time period at the test temperature ± 2 °C. The test is completed when altogether 15 temperature cycles (see Figure 5) are completed.

7.3 Inspection

After the test the collector is visually inspected for any changes or damages like permanent deformation, glass or adhesive brakeage any structural failure, any burning, scorching, or heat shrinkage, outgassing and any effect likely to impair the serviceability of the collector.

8. Final assessment

After the collector went through all accelerating aging tests the following final tests will be carried out to assess the impact of the previous test on the performance of the collector:

1. Thermal performance test according to ISO 9806, section 20 "Performance testing of fluid heating collectors" to assess the thermal performance prior to aging testing.
2. Mechanical load tests according to ISO 9806, section 16 "Mechanical load test with positive or negative pressure" with a load (positive and negative) of 2400 Pa to ensure a minimum resistance against wind and snow loads. The load (positive and negative) of 2400 Pa is applied 10 times.

When the tests have been completed the collector used for the tests is dismantled and inspected. All abnormalities shall be documented and accompanied by photographs. The collector and all of its components shall be described and should be photographed (glazing, absorber, absorber coating, insulation, housing, inlet and outlet ports, glazing supports and retainers, seals, gaskets, back sheet, etc.).

9. Summary and outlook

In the framework of the German research project *Speed*Coll " Development of Accelerated Ageing Tests for Solar Thermal Collectors and their Components” a test procedure for the accelerated aging of collectors has been developed and was carried out. The proposed test conditions of the single tests can be adopted according to specific climatic and operational requirements. Thus the proposed test procedures allow an assessment of the impact of the operation and climatic conditions during the lifetime of the collector.

Currently the test sequences are further developed with in the follow-up research project *Speed*Coll2 "Estimation of the service life of solar collectors and its components". The aim of the project are accelerated aging tests which allow the estimation of the service life of solar collectors and its components depending on the climate and the operation conditions the collectors will be used at.

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