TÜV Rheinland Energie und Umwelt GmbH
Solar Energy

Test Report

Prüfbericht

Freeze resistance tests of Heat Pipes for Solar Collectors following

Frostprüfungen von Wärmerohren für Solarkollektoren in Anlehnung an

DIN EN 12975-2: 2006

TÜV Report No.: 21220036_HPQual

Cologne, 08 January 2013

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Report-No.: 21220036_HPQual

on
Freeze resistance tests of Heat Pipes for Solar Collectors following
Frostprüfungen von Wärmerohren für Solarkollektoren in Anlehnung an
DIN EN 12975-2: 2006

Client: Kunde	Solar Certification Found European Solar Thermal Industry Federation, aisbl (ESTIF) Rue d'Arlon, 63-67 1040 Bruxelles Belgium
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1 Setting of tasks
Aufgabenstellung

The project „HPQual“ is founded by the Solar Certification Found of the European Solar Thermal Industry Federation. After several papers about freeze damages occurred on heat pipes and a first proposal to make the freeze resistance test on heat pipes obligate, the Solar Keymark Network had decided to investigate more work in elaborating a validated test procedure.
The main items of the project proposal for HPQual was to elaborate a detailed test procedure and to validate it with practical tests within three different test labs. So, this project was realized in cooperation between Fraunhofer Institute for Solar Energy Systems (ISE), the Institut für Solarenergieforschung Hameln ISFH and TÜV Rheinland Energie und Umwelt GmbH.
This test report is only covering the validation measurements performed by TÜV Rheinland Energie und Umwelt GmbH.

2 Basis of testing
Grundlagen

DIN EN 12975-1:2006+A1:2010 *„Thermische Solaranlagen und ihre Bauteile- Kollektoren- Teil 1: Allgemeine Anforderungen“*
DIN EN 12975-1:2006+A1:2010 “Thermal solar systems and components - Collectors - Part 1: General requirements”

DIN EN 12975-2:2006 *„Thermische Solaranlagen und ihre Bauteile- Kollektoren- Teil 2: Prüfverfahren“*
DIN EN 12975-2:2006 “Thermal solar systems and components - Collectors - Part 2: Test procedure”

3 Test Samples

Within this project, five different types of heat pipes were examined by each laboratory. 50% of each type were pre-aged, the other 50% kept new. Beside heat pipes integrated into all-glass tubes, some uncovered single heat pipes and at TÜV one additional single glass heat pipe were used for the test.

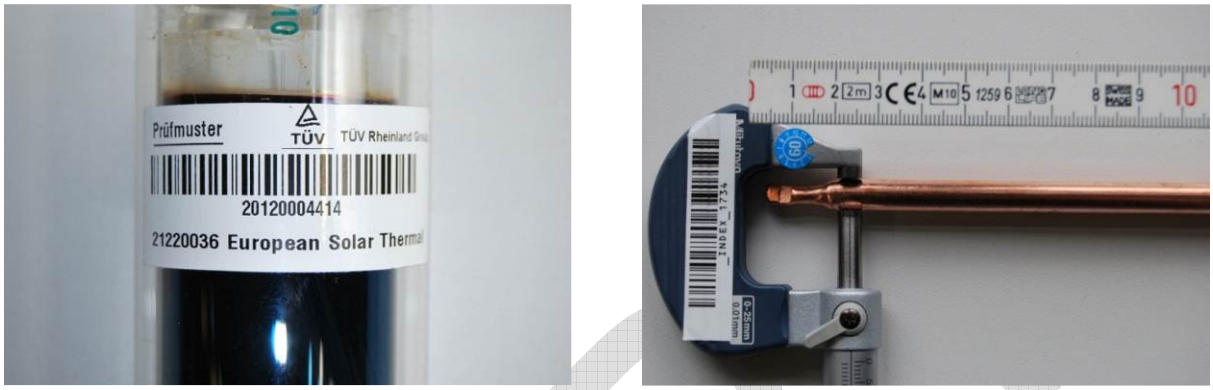


Fig. 01: Type 1: Test samples from TÜV

Fig. 02: Type 2: Test samples from ISFH

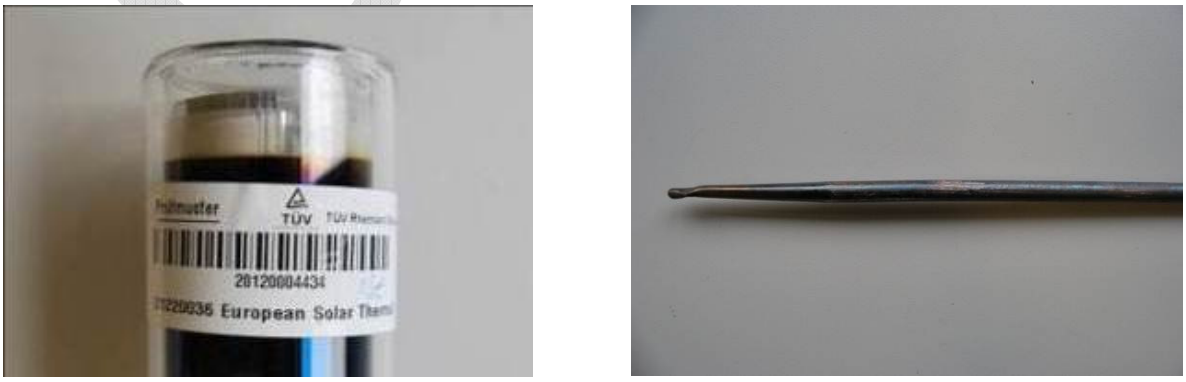


Fig. 03: Type 3: Test samples from ISE

Fig. 04: Type 4: TÜV II, Single glass evacuated tube

Fig. 05: Type 5 and 6: TÜV III, Additional heat pipe tested das single one and assembled into all glass tube

4 Test Procedure

4.1 Initial test procedure

Requirements for freeze resistance test of evacuated tube collectors with Heat Pipes following EN 12975:2006

Evacuated tube collectors are designed for a several year outdoor use under local climate. If the collectors are claimed to be freeze resistant, periods with freezing temperatures shall not effect in permanent damages.

Within the current issue of EN 12975-2, there's no additional test required, if the collector loop will be driven with a water/ glycol mixture. In the latest draft version – elaborated during the past winter- there is now an amendment dealing also with the problem of internal fluids with the risk of freezing: *This test is not intended for use with collectors for which it is clearly stated in the installation manual that they may only be used with an antifreeze fluid* ***unless there's no use of additional liquids with the risk of freezing.***

A test procedure especially developed for heat pipe collectors could only be part of the next revision of the standard.

With some minor adaptations, the existing test procedure out of EN 12975-2:2006 could already be used for freeze resistance testing of heat pipes:

Test parameter	Requirements EN 12975-2	Adapted procedure for Heat Pipe Collectors
Tilt angle	Lowest recommended tilt angle or 30°	Highest recommended tilt angle or 90°
Reference temperature	Fluid within collector loop (absorber)	Fluid within Heat Pipe
Freezing require-ments	> 30 min absorber content (-20 ± 2)°C	> 30 min. Heat Pipe Fluid < -20°C
Thawing require-ments	> 30 min absorber content >10°C	> 30 min. Heat Pipe Fluid > 10°C
No. of Cycles	3	20 (with determination of intermediate state after 3rd cycle)
Cycle duration	< 5 h	ca. 12 h
Total duration	< 24 h	10 Days
Test sample	Complete Collector	Test of single tubes with heat pipes possible
No. of samples	1	Minimum 9 Heat Pipes (include. min. 4 preconditioned ones)

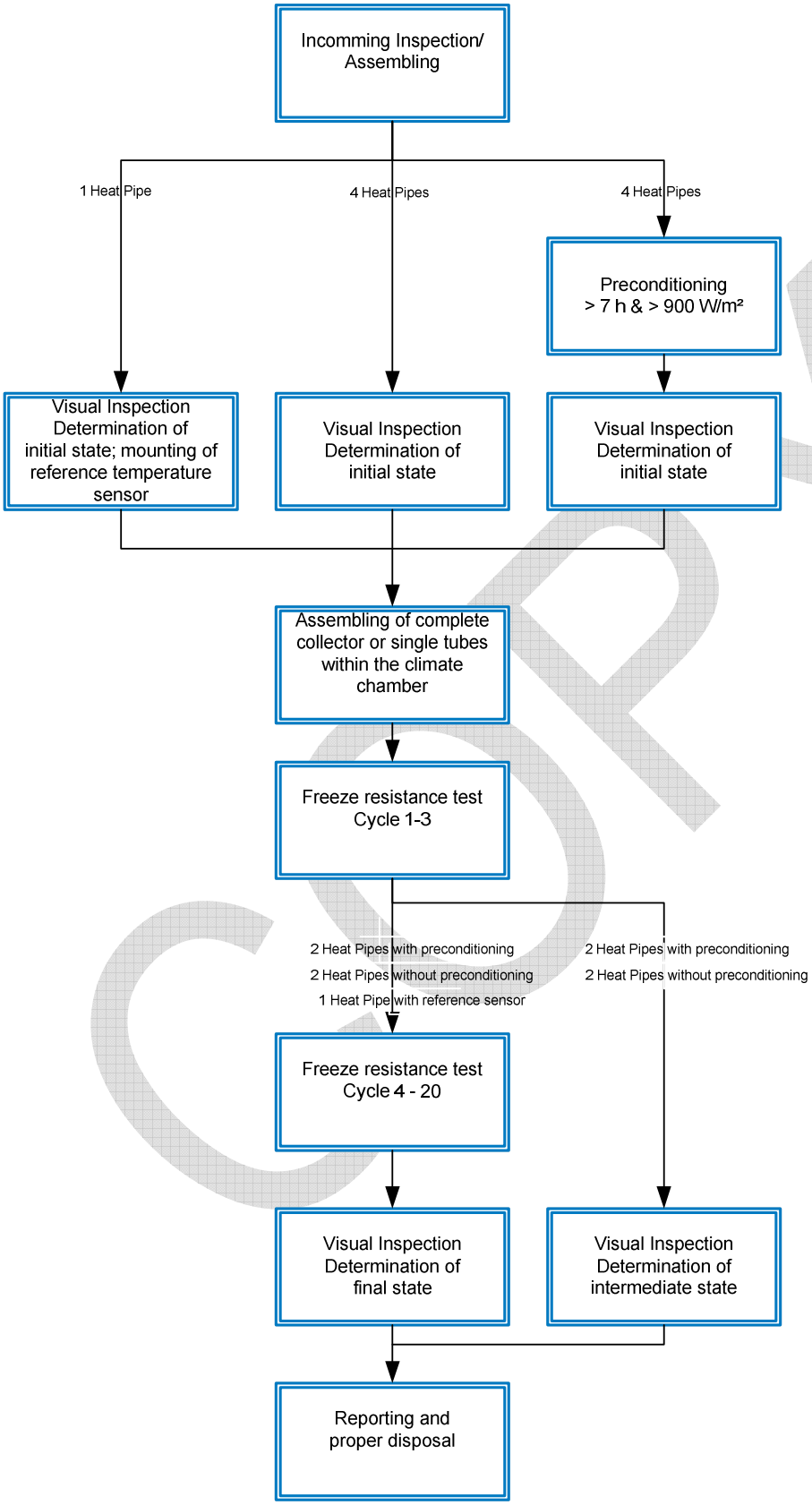


Fig. 06: Test Procedure

Specifics

If not a complete assembled collector will be used for testing, the evacuated tube will be protected against convection between inside and chamber (relevant only for all glass tubes).

As a result, the main heat transfer will proceed into the heat pipe via the condenser. It will be possible to test single evacuated tubes with heat pipes under the same conditions than complete evacuated tube collectors.

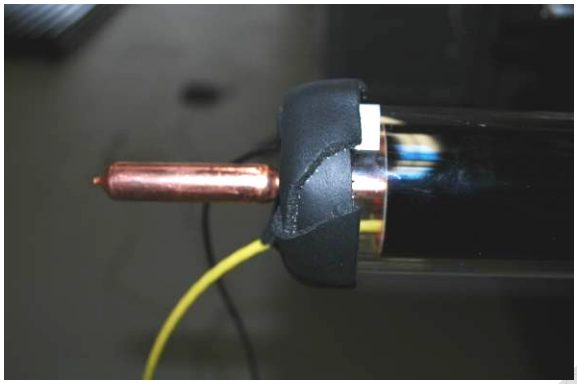


Fig. 07: Prevention of thermal convection

Fig. 08: Reference temperature sensor

To get a sufficient test result, three temperature cycles are not enough. Solar thermal collectors should have a lifetime of more than 20 years, so one freeze cycle per year is an appropriate test criteria.

The heat pipe with the reference temperature sensor will only be used to detect the temperature and won't be evaluated within final inspection.

Fig. 09: After 3 EN Cycles (10 h each)

Fig. 10: After 20 EN Cycles (10h each)

Criteria for acceptance

- No measurable widening of pipe diameter (in due consideration of measuring tolerance)
- No visible damages on heat pipe tube

4.2 Additional specification

4.2.1 Reference temperature sensor

The temperature sensor will be fixed on the lower end of the heat pipe close to the expected maximum level of fluid. The permanent temperature detection during test detected perfectly the point of freezing within the heat pipes (enthalpy for phase changing at or close to 0°C)

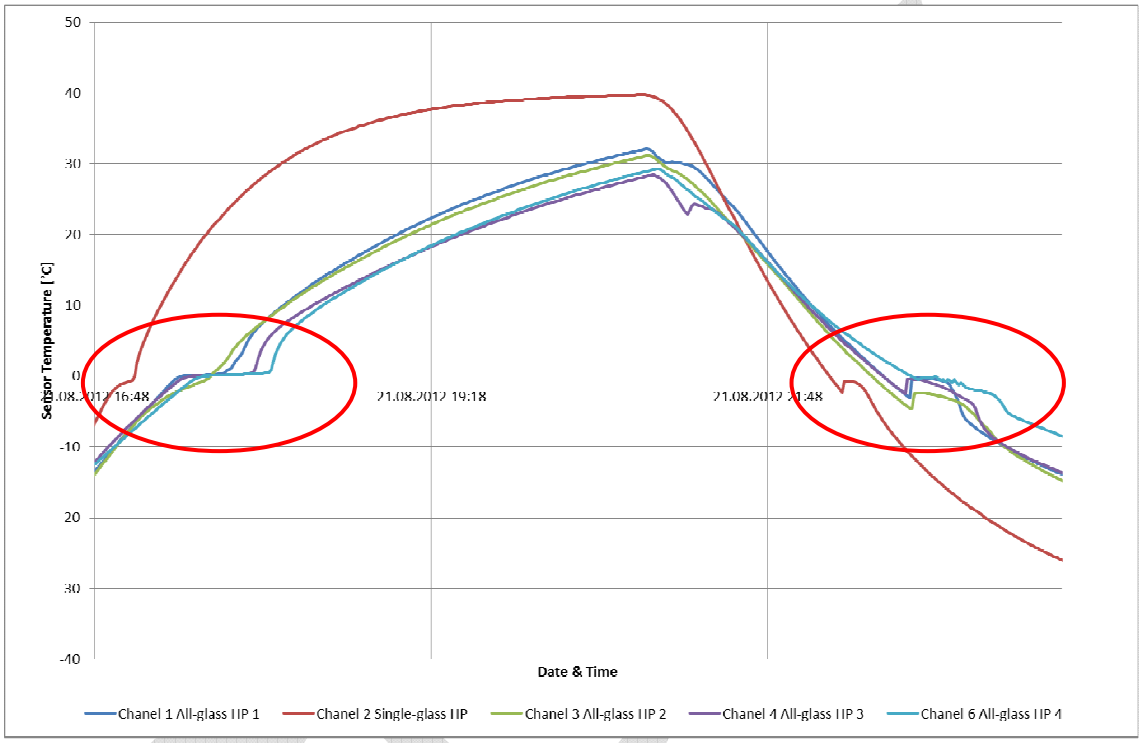


Fig. 11: phase change within heat pipe

4.2.2 Glass metal heat pipes

For the glass metal heat pipe, one sample was opened on the top of the condenser and a temperature sensor was put inside the pipe down to the bottom.

Even there might be not the full quantity of fluid inside the heat pipe any more, there's also a clear point of freezing measurable (see red line within graph above). As this kind of tubes showed always a much lower thermal capacity and time constant as conventional all glass tubes including heat pipes, this special temperature measurement may not be necessary.

4.2.3 *Convection shield*

Because all of the tube caps seal the tubes in an adequate way, no further convection shield was used for test. Only the tubes with the integrated temperature sensor were covered by an adhesive insulation tape.

4.2.4 *Assembling of heat pipes into existing all glass tubes*

As there were only single heat pipes available by one supplier, we've assembled them with heat transfer sheets and all glass tubes by an additional manufacturer to evaluate the behavior under the same conditions than the other heat pipes. Neither the all glass tube with its vacuum nor the heat transfer sheet will have a major influence on the results. It may take a few minutes longer to reach freezing points, but this will be detected by the temperature sensor.

4.2.5 *Pre-conditioning and storage*

The detailed examination of heat pipes and their behavior within QAiST-Project had shown massive degradation effects within the first weeks of operation. Due to the fact, that no one really knows about the consequences for freeze resistance, we've decided to do a full outdoor exposure test before starting freeze resistance test. The former preconditioning in accordance with EN 12975-2 thermal performance detection was supposed to be insufficient.
For detection of discrepancies, 50% of the heat pipes were preconditioned and 50% not.

4.2.6 *Storage of samples*

The assembled heat pipes were stored horizontal after preconditioning.

4.2.7 *Chamber specification*

Test Chamber:	Weiss Umwelttechnik WK 17'/40-100
Operating Range:	-40….+100℃, stability < +- 1K
	10….95 % rel. humidity (not used for freeze tests)
Height:	2400 mm
Width:	2400 mm
Length:	3600 mm

4.3 Outdoor exposure

The outdoor exposure test as preconditioning was made during spring 2012 on a full assembled collector.

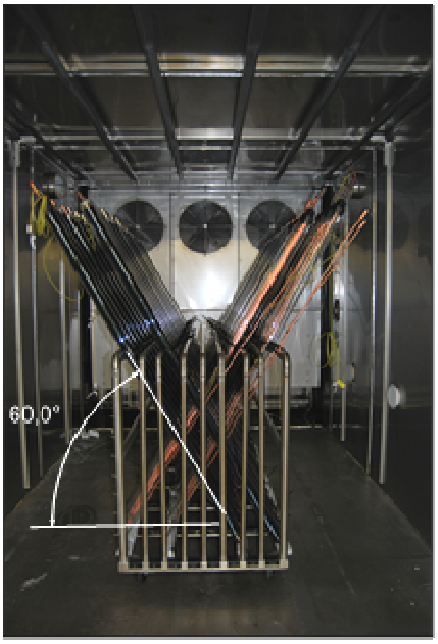
Date begin/ end Datum Start/ Ende	20 March 2012	09 May 2012

Test conditions
Prüfbedingungen

Collector tilt angle [° from horizontal] Neigungswinkel des Kollektors zur Horizontalen in °	35	
Total no. of test days and radiation energy [MJ/m²] Anzahl der Prüftage und Strahlungsenergie	50	900.1
No. of days with more than 14 MJ/m² Anzahl der Tage mit mehr als 14 MJ/m²	34	
No of rain days and total rainfall [mm] Anzahl der Regentage und Gesamtniederschlags-summe	15	163.3
Time period with G>850 W/m² & ta>10°C [h] Zeitabschnitte mit G > 850 W/m² und ta > 10°C	103.3	
	minimum value Mindestwert	maximum value Maximalwert
Ambient temperature of test days [°C] Umgebungstemperatur der Prüftage	0.0	28.3
Ambient temperature during high irradiation > 850 W/m² [°C] Umgebungstemperatur während hoher Einstrahlung	10.7	27.6
Total daily rainfall [mm] Tägliche Niederschlagssumme [mm]	0.0	42.6

4.4 Climate chamber test

4.4.1 Test Setup



The assembled as well as single heat pipes are fixed into a moveable test rig with an inclination of 60°. This value was used as a typical maximum incidence angle for heat pipe collectors. There are nearly no heat pipes declared for vertical wall mounting available on the market.

The reference temperature sensors were connected to a data acquisition system outside the chamber. The sample period was set to 1 minute.

Fig. 12: Test setup

3.3.1 Test cycles

Based on the previous tests at TÜV Rheinland, it was decided to choose a cycle duration of approximately ten hours to guarantee the complete freezing and thawing of the heat pipes. The set temperature was set to -40 °C for freezing and +40 °C for thawing period.

After three cycles, a visual inspection on one of each five tube packages was made.

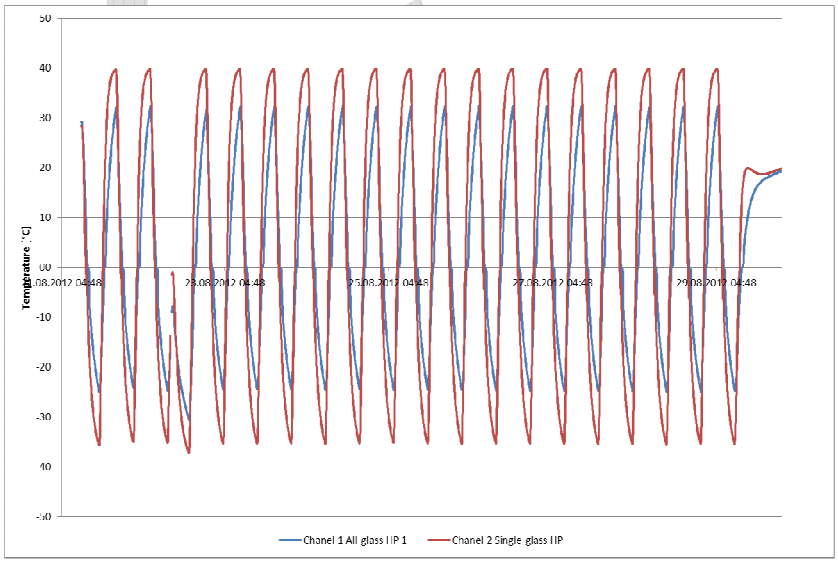


Fig. 13: Temp. Cycles

4.5 Final Inspection

After the last freezing cycle, the chamber was balanced to ambient temperature and the complete test rig was taken out. A detailed final inspection with photo documentation was made for every het pipe. Because of the used TÜV Barcode system, a full traceability to the initial measurements is given.

4.5.1 Type 1 (TÜV)

No widening was detected. All deficiencies are within the overall measurement uncertainty.

Type 1	**TÜV**		diameter	after	
Sample no.	Barcode no.	new/ pre-aged	0 cycles	3 cycles	20 cycles
1	20120004405	new	8.1	no visual problem at one single pipe	8.02
2	20120004406	new			8.08
3	20120004407	new			8
4	20120004408	new			8.07
5	20120004409	new			8.09
6	20120004410	full exposition	8.09	no visual problem at one single pipe	8.11
7	20120004411	full exposition			8.15
8	20120004412	full exposition			8.13
9	20120004413	full exposition			8.09
10	20120004414	full exposition			8.07

4.5.2 Type 2 (ISFH)

No widening was detected. All deficiencies are within the overall measurement uncertainty.

Type 2	**ISFH**		diameter	after	
Sample num	Barcode	new/ pre-aged	0 cycles	3 cycles	20 cycles
1	20120004415	new	8.05	no visual problem at one single pipe	8.04
2	20120004416	new			8.03
3	20120004417	new			8.01
4	20120004418	new			8.03
5	20120004419	new			8.02
6	20120004420	full exposition	8.06	no visual problem at one single pipe	8.04
7	20120004421	full exposition			8.03
8	20120004422	full exposition			8.03
9	20120004423	full exposition			8.05
10	20120004424	full exposition			8.04

4.5.3 Type 3 (ISE)

No widening was detected. All deficiencies are within the overall measurement uncertainty.

Because of conic shape of head pipe bottom, the measurement of diameter is more difficult. The high precision mircometer calliper is not possible to use, only a regular calliper.

Type 3	**ISE**		diameter	after	
Sample num	Barcode	new/ pre-aged	0 cycles	3 cycles	20 cycles
1	20120004425	new	8.02	no visual problem at one single pipe	8.02
2	20120004426	new			8.02
3	20120004427	new			8.03
4	20120004428	new			8.02
5	20120004429	new			8.02
6	20120004430	full exposition	8.05	no visual problem at one single pipe	8.01
7	20120004431	full exposition			8.03
8	20120004432	full exposition			8.02
9	20120004433	full exposition			8.04
10	20120004434	full exposition			8.05

4.5.4 Type 4 (TÜV II, single glass tube)

No widening was detected. All deficiencies are within the overall measurement uncertainty

Because of the construction “single glass tube” a comparison after 0 and 20 cycles was not possible. The heat pipe didn’t show any problems. Even the additional single heat pipes with destroyed glass tube didn’t show any problems.

This sample was only used to show the applicability of the test procedure also for single glass tubes!

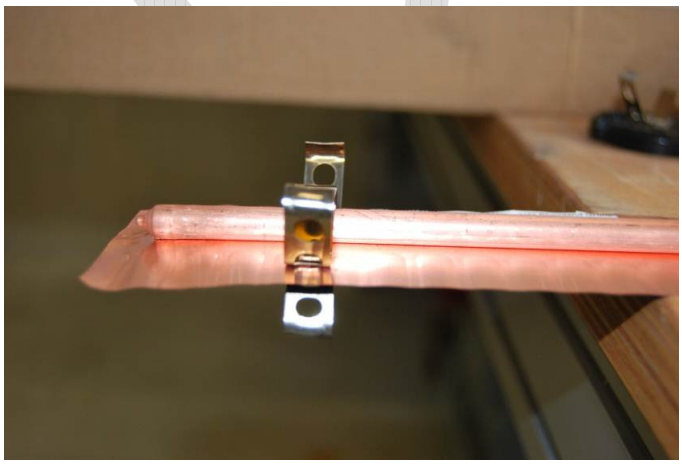


Fig. 14: single glass tube/ heat pipe

4.5.5 Type 5 (TÜV III, assembled)

Widening was detected. It need to be discussed, if this value is a failure after 20 cycles.

Type 5	**TÜV III assembled**		diameter	after	
Sample num	Barcode	new/ pre-aged	0 cycles	3 cycles	20 cycles
1	20120004435	new	8.01	no visual problem at one single pipe	8.5
2	20120004436	new			8.37
3	20120004437	new			8.37
4	20120004438	new			8.37
5	20120004439	new			8.37
6	20120004440	full exposition	8.09	no visual problem at one single pipe	8.45
7	20120004441	full exposition			8.37
8	20120004442	full exposition			8.37
9	20120004443	full exposition			8.37
10	20120004444	full exposition			8.37

4.5.6 Type 6 (TÜV III, single heat pipe)

Massive widening was detected. Definitely a failed test, but with a more critical test setup.

Type 6	**TÜV III single HP**		diameter after		
Sample num	Barcode	new/ pre-aged	0 cycles	3 cycles	20 cycles
1	nur HP	new	8		9
2	nur HP	new	8.01		9.86

Fig. 15: Comparison of assembled and single heat pipe after 20 test cycles.

This additional test sample in combination with the different test set ups is a perfect indicator for a reasonable pass/ fail criteria. From our point of view. Type 5 had failed, so the maximum allowed widening value under consideration of measurement uncertainties shall not be more than 2 mm.

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4.6 Conclusion

The freeze test procedure used for this verification test seems to be a feasible way to determine the freeze resistance of heat pipes. Even, if no assembled heat pipes clearly failed, former test series had shown, that bad products will fail this test by using 20 test cycles.

There is a difference, if the heat pipes will be tested as single ones or included into an evacuated tube. The test with single heat pipes is much more critical and could may be used, if the manufacturer is asking for. The test duration will be much lower and a combination with PV module cycling test may be possible.

Furthermore, a manufacturer had told us, that the orientation of storing after preconditioning (horizontal/ vertical) could have an influence on the results. Because of that, it will be recommended to store the heat pipes with a minimum tilt angle of e.g. 20° to ensure , that the fluid with all inhibitors and particles is completely inside the bottom of the pipe without any risk of "sedimentation" before starting the test.

4.7 Outlook

For traceability, the heat pipes should be clearly marked/ labeled by the manufacturer and the complete specification (materials, fluids, additives) together with their tolerances shall be given.
A clear pass/ fail criteria need to be defined. The definition used in EN 12975-1:2006 chapter 5.3.10: "*The pass criterion is no major failure as defined in 5.3.1 after three freeze-thaw cycles*." and the relevant part out of 5.3.1 " *if absorber leakage occurs*" are not an adequate definition!

The recent and past test sequences had shown, that the tube widening is usual less than 0.1 or more than 0.3 mm (up to the bursting of the heat pipe). Our suggestion will be now to use 0.2 mm as maximum allowed diameter widening. There's no problem with measurement uncertainty, production tolerances and conventional caliper use. Furthermore the value is visible.

One further problem is to define the points for initial measurement of diameter. If it is a nearly perfect shaped cylindrical tube, the position for initial measurement doesn't matter. If we've got conic shaped ones, it will be very important.

Beside retaining some conditioned heat pipes for comparative measurements (also necessary for heat pipes integrated into single glass tubes), the initial measurement should be done at precise defined positions like suggested in the following picture. If it is no heat pipe with a long cylindrical shape (like the ISE sample), the point of measurement should be based on the co-planar area of the end of the tube. For conic shaped tubes, the comparative measurement between a preconditioned one with and without freeze testing seems to be the only solution.

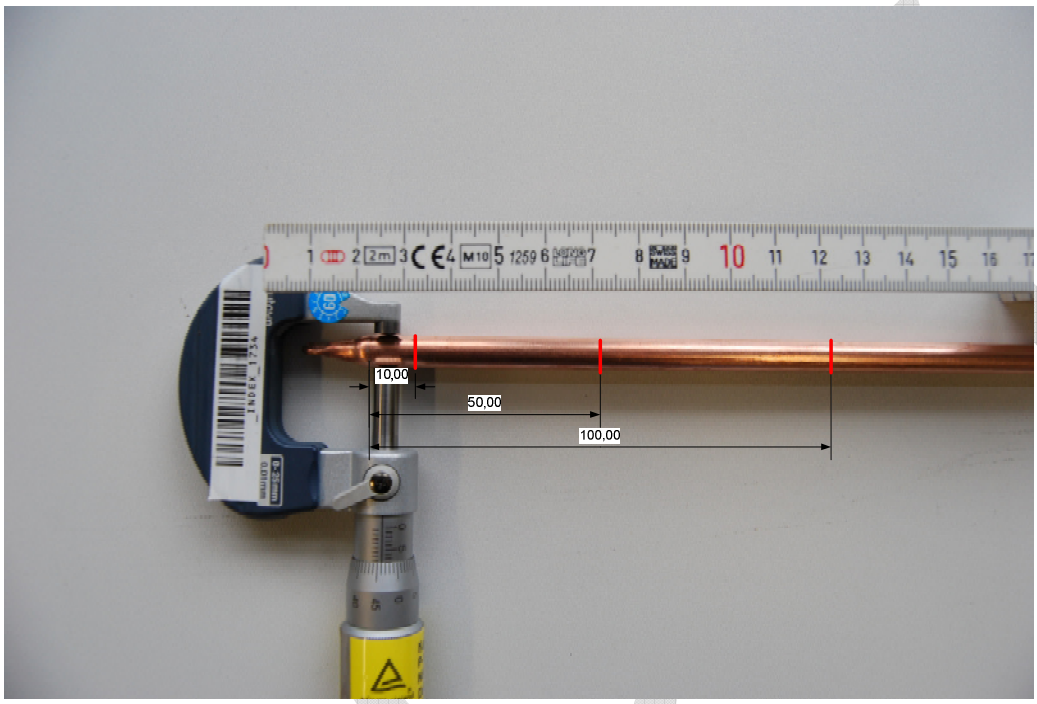

Fig. 16: Definition of initial positions for diameter determination [mm]

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5 General remarks
Bemerkungen

All results only refer to the test samples that were subjected to testing.

We thank the Solar Certification Found for their financial support.

Cologne, 08 January 2013

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