Quality Assurance in solar thermal heating and cooling technology

Keeping track with recent and upcoming developments

Summary report
Freeze resistance test of heat pipe evacuated tube collectors

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Background

After the extremely cold winter of 2009/2010 massive frost damage to a larger evacuated tube collector field was reported in Bavaria. Examinations by the proprietor on site showed that a large number of collector heat pipes had burst as a result of the frost. In order to be able to assess the relevance of this matter, TÜV Rheinland decided to examine the issue in more detail. Previously only the heat transfer fluid in the solar loop or the self-emptying function was taken into account in the evaluation of frost resistance. The heat transfer fluid within the heat pipes was not considered.

Test Basis

Various frost/thaw cycles are to be carried out in the climate chambers of TÜV Rheinland in accordance with EN 12975-2 and IEC 61215. Beside the general question of the risk of heat-pipes freezing, these experiments should demonstrate whether the current test procedures for heat pipes and heat pipe collectors can be used.

Consequently different issues result. Firstly, whether the duration of the cycle time as recommended in the standard EN 12975 is also sufficient for tube collectors with heat pipes and secondly whether it may prove necessary to increase the number of cycles. Furthermore it should be clarified whether the specifications in the PV standard with regard to the freeze resistance testing can also be used, as appropriate, for solar thermal tube collectors. It also appears to be necessary to consider to what extent the individual test results differ when heat pipes or heat pipes in evacuated glass tubes or fully assembled panels are used in the climate chamber test.

Test Series

1.1 Test Series 1

In the first experiment, an initial impression should be gained as to what happens within the individual heat pipes with different freeze / thaw cycles.

In a first step, 5 heat-pipes from 6 different collector manufacturers were tested without evacuated glass tubes in a climate chamber in accordance with the test conditions specified in Chapter 5.8.3 of EN 12975-2 (3 cycles, -20 ° C /> 10 °C). Subsequently, two heat-pipes were each subjected to a further temperature cycling test according to IEC 61215 TC50 (50 cycles from -40 ... 85 °C).

In order to detect damage or changes to the material at an early stage, the diameter of the fluid-filled area at the lower end of each of the heat pipes was documented before the test.

Figure 1: Climate chamber for temperature cycling test in SEACC laboratory

1.2 Evaluation

After the three test cycles according to EN 12975-2 there was a significantly measurable expansion in the copper tube at the lower end of the heat-pipes from 5 of the 6 manufacturers.

After 50 cycles according to IEC 61215 at least one of the two pipes from the 5 suppliers burst. Figure 1 below shows the average percentage deviation of the diameter, based on the initial state.

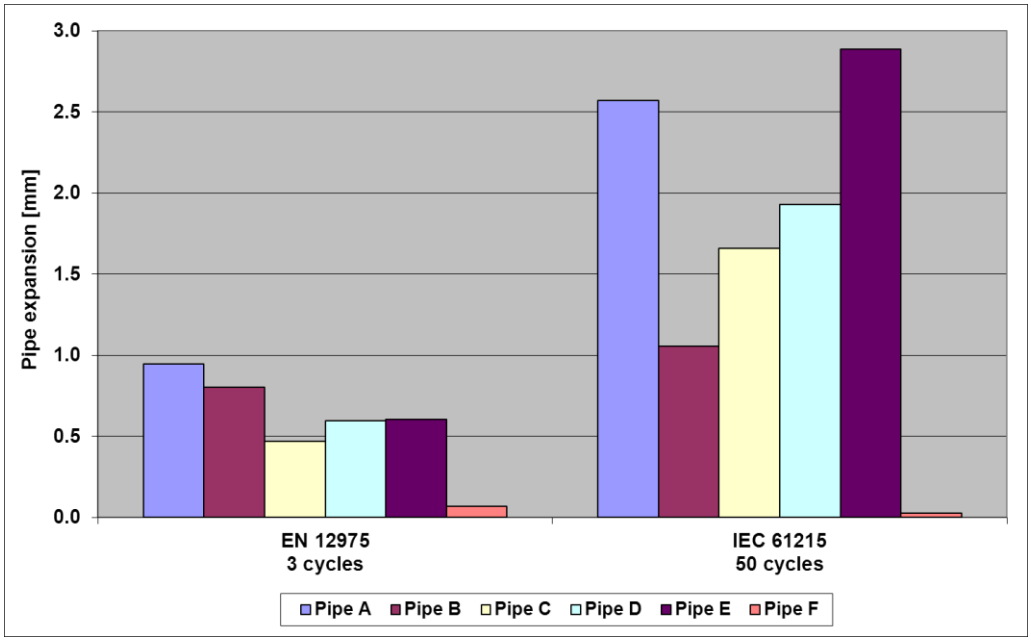
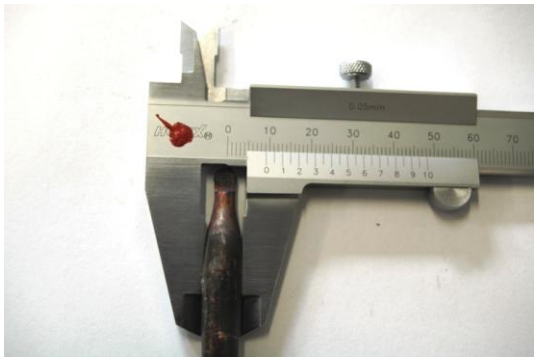


Figure 2: Comparison of standards

It is clear that as a general rule extremely severe deformation can occur even leading to destruction (see Figures 2 & 3). There was only one manufacturer whose heat pipes survived both test sequences without measurable or noticeable distortion.



Figures 3 & 4: Frost damage after climate chamber test (EN 12975-2 & TC50)

The extremely high failure rate in this first series of experiments led us to the conclusion that on the one hand there is a general risk of heat-pipes freezing, but that arguably on the other hand the particular temperature distribution in evacuated tubes with heat pipes must be considered. This means that in a second series of tests, the cooling “power” respectively the cold air temperature should be almost exclusively introduced into the heat pipe through the condenser.

1.3 **Test Series 2**

In this series of tests 8 heat-pipes with evacuated glass tube collectors from 4 different manufacturers were examined as well as two completely assembled evacuated tube collectors of the same design with 10 tubes. In both complete collectors the outermost and the middle tubes and the individual tubes for climate chamber tests were equipped with up to three PT-100 temperature sensors. The sensor positions can be found in the legend entry of Figure 2. The abbreviation before the slash denotes the position of the collector tube (a = outer, m = middle). The designations after the slash indicate the exact position of the PT-100 temperature sensor in the tube (b = bottom, o = top). The open glass tubes at the top or at the end of the capacitor are sealed with duct tape to prevent air exchange between the tube interior and the environment. However, the capacitor remains uncovered.

A complete cycle of 10 hours is required in order to achieve complete freezing (≤ -10 °C) or thawing (≥ 10 °C) of the heat pipes. Through this the actual risk of mounted collectors freezing is to be estimated. According to the collector standard EN 12975-2 three complete cycles are performed.

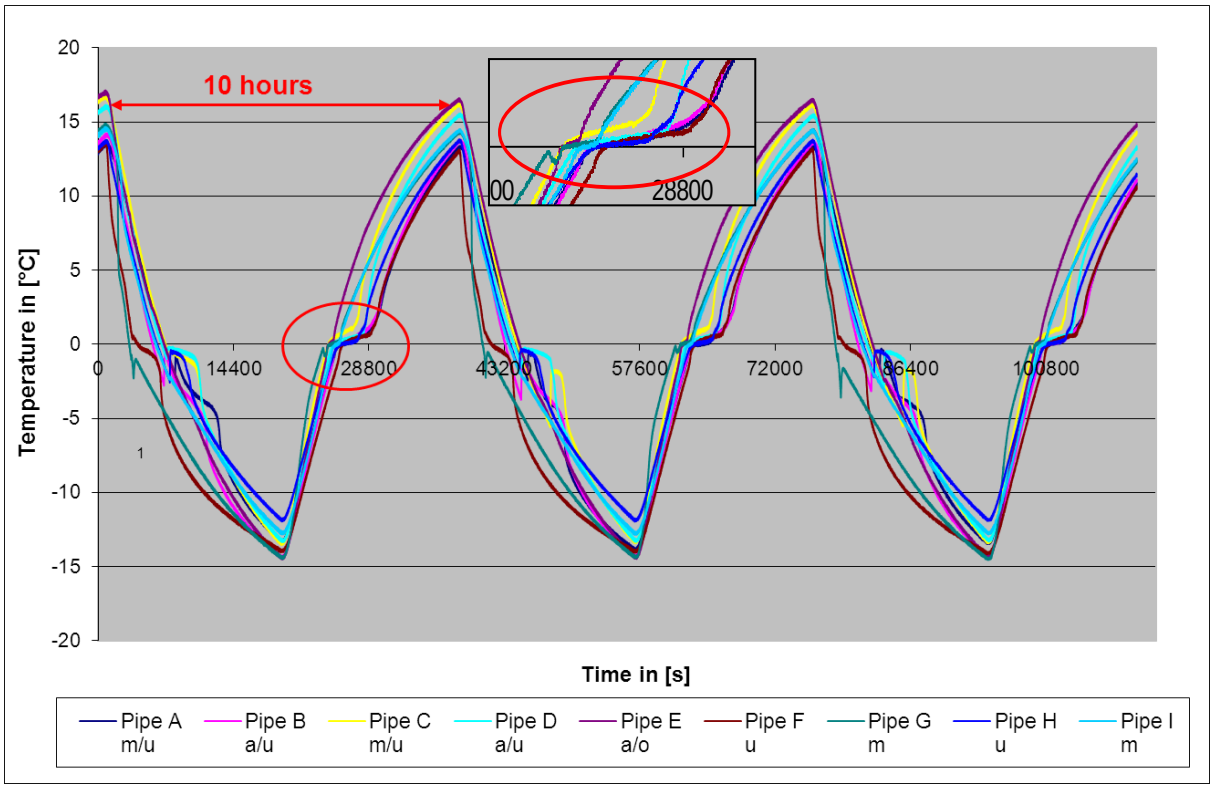


Figure 5: Freeze / thaw cycle behaviour in the individual heat pipes

1.4 **Evaluation**

The diagram above illustrates the complete three cycles for all evacuated tubes and collectors used. It is clear that the previously defined freeze and thaw limits lead to the desired aggregate state change in all tubes in the specified cycle time of 10 hours. Even if it is obvious that the outer collector tubes and the individual tubes can follow the temperature changes more rapidly, the differences in view of the cycle duration are low.

It therefore suffices to use convection-free sealed tubes with an exposed capacitor in the frost test, consequently keeping the need for the climate chamber and thus the test costs low.

Measurements at the lower end of the heat pipe are very good for identifying the duration of the aggregate change as a practically horizontal line, especially during the thaw phase. On the one hand this shows that the heat transfer media freezes and furthermore that this also takes place in almost all heat pipes at around 0° C. If there are no special constructive precautions against freeze damages, the use of antifreeze inside the heat pipe to reduce the freezing point is a must.

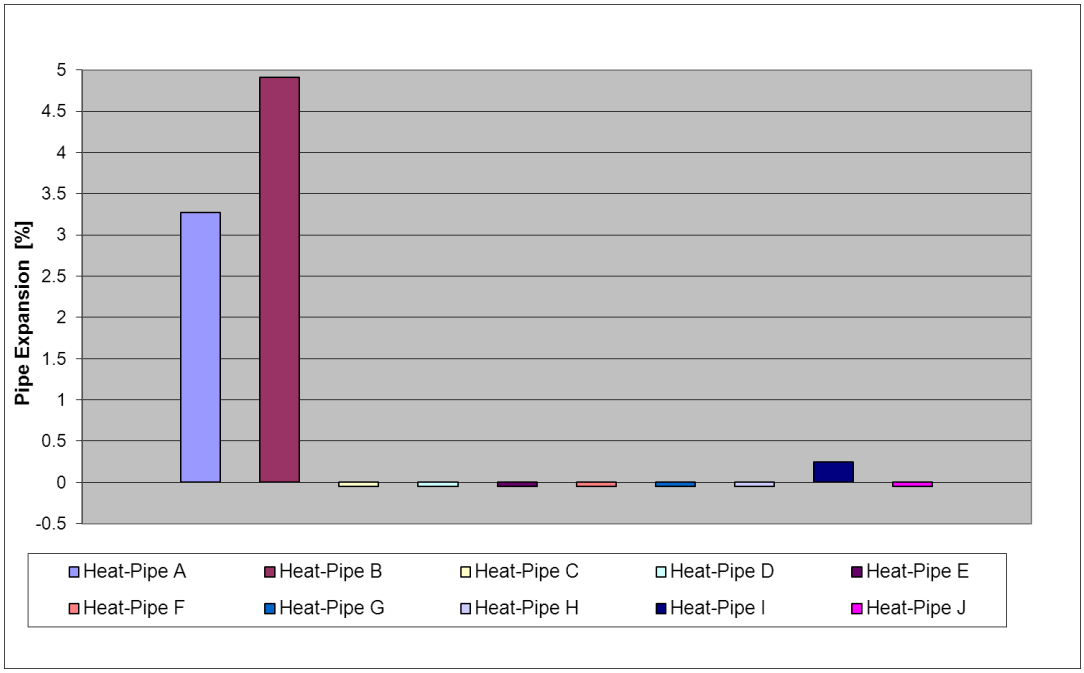


Figure 6: comparison of percentage deviations before and after testing

In Figure 6, the percentage deviations of the two test series are compared. It appears that in spite of the insulating effect of the vacuum, and after only three test cycles, deformation of individual heat pipes has already taken place.

Conclusion and Outlook

The experiments conducted have shown that in general heat pipes are susceptible to frost. Furthermore it became apparent that the cycle duration stated in EN 12975 - 2 of at least 60 minutes for heat pipe collectors does not even remotely suffice. A cycle of at least 10 hours is required in order to achieve complete freezing or thawing of the heat pipe. Only then can it be ensured that temperatures of -10°C to +10°C are achieved in the heat pipe.

In the same manner it became clear that on the one hand the testing of an individual heat pipe without a glass tube does not lead to realistic results, on the other hand, however, it is also not necessary to test a completely mounted collector. The use of single heat pipes with evacuated tubes represents a good compromise between the expenditure and space required and realistic testing. For all glass tube heat pipe construction open to surrounding, an adequate convection shield shall be used.

The failure rate within the test series 2 could increase further if the number of cycles is increased. This should be confirmed through further testing in the near future (with a higher number of cycles). A combination of the test sequence with that for PV modules is not possible due to the increasing cycle duration for glass tube – heat pipe combination.

Within the new standard draft for EN 12975-2 and ISO 9806, the following sentence was integrated into chapter 5.9.1 to point out the need of freeze testing for heat pipes:

“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 or air unless there’s no use of additional liquids with the risk of freezing as e.g. in some heat pipes.”

The first draft for a new test procedure is presented as Annex 2. This procedure need to be further developed and verified by additional test laboratories. The aim is to include the new test procedure into the solar Keymark scheme rules until the next standard revision will be done.

Acknowledgements

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Annex 1: Scientific Poster, German Otti Symposium 2011

1. Poster Award
National ST-Symposium
Bad Staffelstein, 2011

Freeze resistance test of heat pipe evacuated tube collectors; *now a question* of the heat transfer fluid used !

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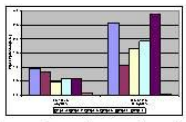
After the extremely cold winter 2009/2010 massive frost damage to a larger evacuated tube collector field was reported in Bavaria. Examinations by the proprietor on site showed that a large number of collector heat pipes had burst as a result of the frost. In order to be able to assess the relevance of this matter, TÜV Rheinland decided to examine the issue in more detail.

At present the instruction that the collector loop must be operated with a glycol-water mixture is sufficient for positive evaluation of the frost resistance. This paper should show whether in fact this does always suffice.

Freeze resistance testing of individual heat pipes

In the first series of tests 30 individual heat pipes from 6 different manufacturers were subjected to both freeze resistance testing in accordance with EN 12975-2 with 3 cycles, and also to thermal cycling test in accordance with IEC 61215 with 50 cycles in a climatic chamber .

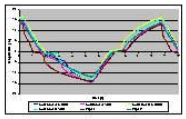
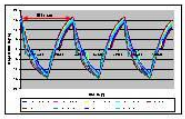



All heat pipes of 5 manufacturers showed expansion after only 3 cycles in accordance with the collector standard and virtually all heat pipes from these manufacturers burst after 50 PV IEC cycles.


Determination of suitable test sequences

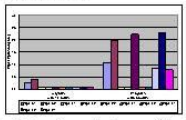
Should all these heat pipes really have frost problems in practice, then considerably more cases of damage could certainly be expected. For this reason it was decided to perform a second series of tests with two completely mounted collectors and also with heat pipes installed completely in the evacuated tubes. In order to adapt the conditions of the individual heat pipe to the conditions of the pipes installed in the collectors, the aperture in the evacuated tubes below the condenser was sealed convection-tight with insulating tape. A virtually vertical assembly was selected. Furthermore individual heat pipes both in the collectors and mounted individually were fitted with temperature sensors.

The following diagram shows the temperature pattern in both the lower area of the individual heat pipes and also the lower area of the individual heat pipes of the two completely mounted collectors. As the freezing and thawing rates only depend on the type of mounting to a slight extent, extensive complete testing is not necessary.

Freeze resistance testing of complete heat-pipe evacuated tubes with adapted cycle duration

As the three frost cycles with an extended cycle duration on the basis of EN 12975-2 only led to distortion with pipes of one of the 6 manufacturers, a further series of tests with 21 cycles was only carried out on individual heat-pipe evacuated tubes.

After this series of tests 50% of the pipes had considerable problems with the freeze resistance testing.

This shows that three frost cycles do not suffice for reliable confirmation of the frost resistance. The point is not to test everything to the point of destruction, but to develop an effective test procedure and to support end customers in the selection of collectors which are suitable for their climate.

The series of tests have shown that heat pipes in general have a risk of freezing and it need to be evaluated, if this risk results in damages or not. Furthermore it became apparent that the cycle duration of at least 60 minutes for heat pipe collectors stated in EN 12975- 2 does not even remotely suffice. A cycle of eight to ten hours is required in order to achieve complete freezing or thawing. Only then can it be ensured that temperatures of -10° C and + 10° C are reached in the heat pipe.

In the same manner it could be determined that on the one hand testing of an individual heat pipe without a glass tube does not lead to realistic results, on the other hand, however, it is also not necessary to test a completely mounted collector. The use of individual convection resistant heat pipes with evacuated tubes represents a good compromise between both expenditure and the space required , and realistic testing.

A combination of the test sequence with that for PV-modules is not possible as a result of the requisite cycle duration.

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Annex 2: First Draft 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.

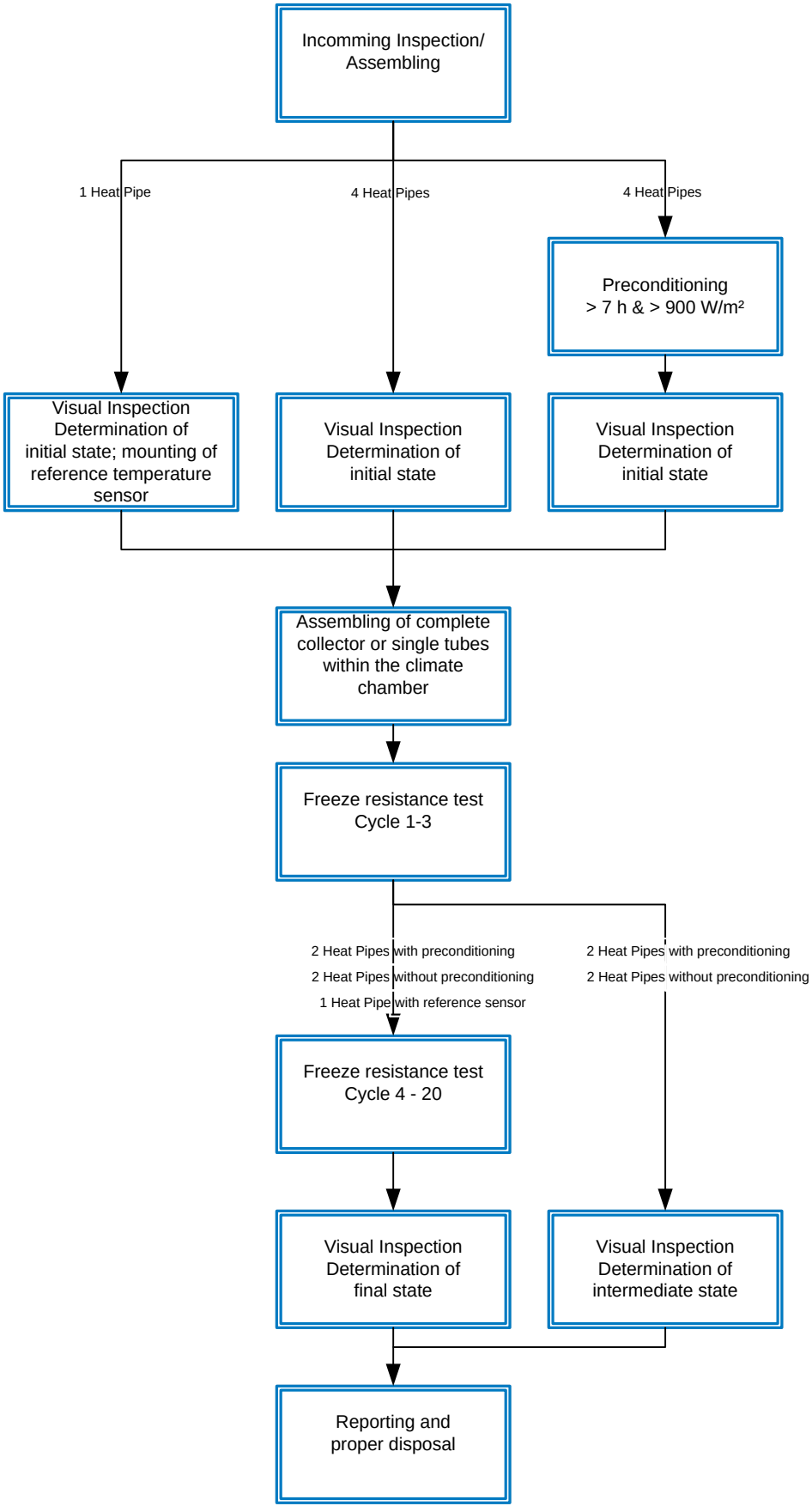
Within the current issue of EN 12975-2, there's no additional test required, if the collector loop will be driven with a water/ glycol mixture. In the latest draft version – elaborated during the past winter- there is now an amendment dealing also with the problem of internal fluids with the risk of 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 requirements	> 30 min absorber content (-20 ± 2)°C	> 30 min. Heat Pipe Fluid < -20°C
Thawing requirements	> 30 min absorber content >10°C	> 30 min. Heat Pipe Fluid > 10°C
No. of Cycles	3	20 (with determination of intermediate state after 3. 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 (including min. 4 preconditioned ones)

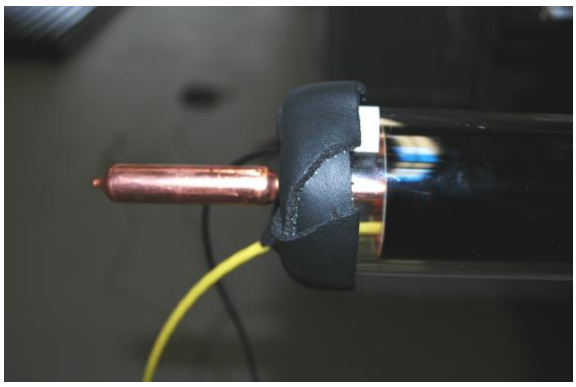
Enclosed, you will find the test structure for freeze resistance tests on heat pipe evacuated tube collectors:


Incomming Inspection/ Assembling
1 Heat Pipe
4 Heat Pipes
4 Heat Pipes
Preconditioning
> 7 h & > 900 W/m²
Visual Inspection Determination of initial state; mounting of reference temperature sensor
Visual Inspection Determination of initial state
Visual Inspection Determination of initial state
Assembling of complete collector or single tubes within the climate chamber
Freeze resistance test Cycle 1-3
2 Heat Pipes with preconditioning
2 Heat Pipes without preconditioning
1 Heat Pipe with reference sensor
2 Heat Pipes with preconditioning
2 Heat Pipes without preconditioning
Freeze resistance test Cycle 4 - 20
Visual Inspection Determination of final state
Visual Inspection Determination of intermediate state
Reporting and proper disposal

Specifics

If not a complete assembled collector will be used for testing, the evacuated tube will be protected against convection between inside and chamber.

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.



Prevention of thermal convection

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.

After 3 EN Cycles (10 h each)

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