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Solar energy — Collector components and materials —

Part 3:
Absorber surface durability

Energie solaire — Composants et matériaux du collecteur —

Partie 3: Durabilité de la surface de l'absorbeur

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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 180, *Solar energy*.

ISO 22975 consists of the following parts, under the general title *Solar energy — Collector components and materials*:

— *Part 3: Absorber surface durability*

The following parts are under preparation:

— *Part 1: Evacuated tubes – Durability and performance*

— *Part 2: Heat-pipe for solar thermal application — Durability and performance*

Introduction

To effectively select, use and maintain a material in a given application, its degradation under service conditions must be predicted prior to use. Preferably, the durability of the material should be expressed quantitatively in terms of an expected service life. Durability in this case is the ability of a material to withstand deterioration caused by external factors in the environment, which may influence the performance of the material under service conditions. Service life is defined as the period of time after installation during which specific material properties important for the performance of the material meet or exceed minimum acceptable values.

The service life of a material is, thus, not solely dependent on its physical and chemical properties, but also on its performance requirement in the application considered, and on the external environmental factors, which influence performance under service conditions. In design work, the important question is if a specific material can be expected to have a service life longer than a certain value, the so-called design service life; the latter dictated by life cost considerations taking into account the total system. Service life assessment may be based on feed-back data from practice or on results from so-called qualification or acceptance durability tests.

The present recommended qualification procedure for solar absorber surface durability is based on the conduct of a series of short-term durability tests. During a test the optical performance of the absorber surface tested is determined by measuring its solar absorptance and thermal emittance. From the loss in optical performance of the absorber surface, its failure time in the test performed is assessed and compared with the shortest acceptable failure time set by the design service life of the absorber. Design service life, performance requirement defining failure time in terms of loss in optical performance, classification of type and levels of environmental stress are set under the assumption, that the absorber surface tested will be installed in a vented flat plate solar collector for use in domestic hot water systems and combisystems or under similar operating conditions.

The recommended qualification procedure may favourably be used in the development and validation of new kinds of absorber surfaces. From the results of tests, it can be concluded whether it is likely that an absorber surface tested may meet the requirement for an acceptable service life also in practice. The recommended durability testing procedure has proved to give results in fairly good agreement, both qualitatively and quantitatively, with what has actually been observed on absorber surfaces tested for longer time periods in solar collectors working under conditions corresponding to that in a typical domestic solar hot water system or combisystem. Nevertheless, if the tested absorber could not be qualified by present procedure, a more comprehensive investigation on durability is recommended and can still lead to a qualification.

The present procedure consists of three parts to test the absorber with respect to its stability against high temperature, against high humidity and condensation and against corrosion caused by atmospheric sulfur dioxide. The three parts are independent and can be assessed individually.

Solar energy — Collector components and materials —

Part 3:
Absorber surface durability

1 Scope

This part of ISO 22975 is applicable to the determination of the long term behaviour and service life of selective solar absorbers for use in vented flat plate solar collectors working under conditions corresponding to that in a typical solar domestic hot water system or combisystem.

This part of ISO 22975 specifies a failure criterion of a solar absorber based on changes in optical performance of the absorber. The optical properties of interest are solar absorptance and thermal emittance.

This part of ISO 22975 specifies durability testing procedures focused on resistance to high temperatures and condensation of water on the absorber surface as well as high humidity in the presence of sulfur dioxide.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4624, *Paints and varnishes — Pull-off test for adhesion*

ISO 8407, *Corrosion of metals and alloys — Removal of corrosion products from corrosion test specimens*

ISO 9050, *Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors*

ISO 10062, *Corrosion tests in artificial atmosphere at very low concentrations of polluting gas(es)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
design service life
time period of exposure under service conditions after installation during which the absorber surface is expected to meet the performance requirement

3.2
failure time
time period of exposure in the test at which the performance requirement limit is reached

3.3
solar absorptance, α_S
fraction of solar radiation energy absorbed by an absorber surface

3.4
thermal emittance, ε

ratio between the energy per unit area radiated by a surface at a given temperature and the corresponding energy radiated by a perfect black body at the same temperature

3.5
performance criterion function

PC

change in performance of an absorber surface in terms of changes in solar absorptance and thermal emittance

4 Requirements and classification

4.1 For classification of the durability of the absorber surface, the following performance requirement shall apply:

$$PC = -\Delta\alpha_s + 0{,}50\Delta\varepsilon \leq 0{,}05 \tag{1}$$

where

$\Delta\alpha_s$ is the change in the solar absorptance defined as

$$\Delta\alpha_s = \alpha_{s,t} - \alpha_{s,i} \tag{2}$$

with $\alpha_{s,t}$ equal to the value of the solar absorptance at the actual time of the test or at service, and

with $\alpha_{s,i}$ equal to the initial value of solar absorptance

where

$\Delta\varepsilon$ is the change in the thermal emittance

$$\Delta\varepsilon = \varepsilon_t - \varepsilon_i \tag{3}$$

with ε_t equal to the value of the thermal emittance at the actual time of the test or at service and

with ε_i equal to the initial value of thermal emittance.

NOTE 1 This performance criterion function is primarily based on location averaged values of the performance of typical solar domestic hot water systems and combisystems.[4] But, in the IEA Task 10 testing procedure referred to, a slightly different definition of PC is used, namely $PC = -\Delta\alpha_s - 0{,}25 \times \Delta\varepsilon$. Investigations made by the IEA MSTC group, however, showed that a weighting factor of 0,5 for the thermal emittance is more appropriate.[9]

NOTE 2 Higher values for the PC function may be used if considered more appropriate. $PC < 0{,}10$ should mean that the optical performance of absorber surface, and thus also the performance of solar domestic hot water system and combisystems, is allowed to be reduced to a level equal to 90 % of its original value during the design service life time period.[4]

4.2 Before durability testing of an absorber surface, all test specimens, sampled and prepared as specified in 5.1, shall be characterized with respect to their value for solar absorptance, determined as specified in 5.2, and their value for thermal emittance, determined as specified in 5.3.

To be qualified for testing, the set of test specimens shall have a standard deviation in the determined values for solar absorptance of less than 0,01 and for the determined values of thermal emittance a standard deviation less than 0,04.

4.3 For coated absorber surfaces, three extra test specimens shall be prepared and the adhesion of coating on those test specimens shall be assessed, as specified in 5.5.

For the absorber to be qualified for testing, the adhesion of coating shall be > 0,15 MPa for all test specimens (ISO 4624).

NOTE If considered accurate enough, the adhesion of the coating may be assessed by a more simple method. The method of ISO 2409[1] may be used and the requirement for satisfactory adhesion be set at the degree of 1. Alternatively, some suitable method in ISO 2819[2] may be used.

4.4 For an absorber surface to be qualified with respect to its thermal stability, the procedure of durability testing as specified in Clause 6 shall be applied.

An absorber surface with sufficient thermal stability shall meet the requirement for test results as is specified in 6.4.

4.5 For an absorber surface to be qualified with respect to its resistance to condensed water when used in a non-airtight solar collector with more or less uncontrolled ventilation of air in the solar collector, the procedure of durability testing as specified in Clause 7 shall be applied.

An absorber surface with sufficient resistance to condensed water shall meet the requirements for test results as are specified in 7.4.

4.6 If an absorber surface should be qualified with respect to its resistance to degradation caused by sulfur dioxide as an airborne pollutant, the procedure of durability testing as specified in Clause 8 shall be applied (optionally).

An absorber surface may be qualified for use in two classes of solar collectors; the two classes representing different severity classes as regards atmospheric corrosivity.

Solar collector of type A: Airtight solar collector or solar collector with controlled ventilation of air in the space between the absorber surface and the cover plate. At the top and at the bottom of the frame of the solar collector, it should be equipped with ventilation holes. The atmospheric corrosivity at the bottom part of the solar collector under service conditions may typically correspond to a corrosion rate of zinc of 0,1 g/m^2 per year.

Solar collector of type B: Non-airtight solar collector with more or less uncontrolled ventilation of air in the solar collector. The atmospheric corrosivity at the bottom part of the solar collector under service conditions corresponds to a corrosion rate of zinc of 0,3 g/m^2 per year.

An absorber surface with sufficient resistance to degradation caused by sulfur dioxide in high humidity air, either regarding only a type A solar collector or regarding both type A and type B solar collectors, shall meet the requirements for test results as are specified in 8.6.

5 Test methods for assessing material properties as measure of absorber performance

5.1 Sampling and preparation of test specimens

For durability testing, test samples with an absorber surface area of preferably (50 × 50) mm shall be prepared. Sampling from larger pieces of absorber plate shall be made in such a way that variation in the optical properties between the different test specimens is minimized. Three extra test samples are also required for the assessment of the adhesion of the coating of un-aged test samples. For execution of the complete programme of durability tests of this recommended procedure, a minimum of 18 test samples are required.

5.2 Sample conditioning

Determine the mean of solar absorptance and the mean of thermal emittance of three samples. Determine the possible maximum absorber temperature for a collector covered with anti-reflection (AR) coating according Table B.1. Temper all 18 samples at this maximum absorber temperature for at least 5 h with an apparatus similar to that described in 6.2. Test three test samples for adhesion according to 5.5 and proceed with the other 15 test samples if they pass the test.

5.3 Solar absorptance

Determine the value of the solar absorptance for each of the 15 test samples from reflectance measurements as specified in A.1. For the complete set of test samples calculate also the mean value and standard deviation of solar absorptance.

5.4 Thermal emittance

Determine also the value for the thermal emittance for each of the 15 test samples as is specified in A.2. For the complete set of test samples calculate also the mean value and the standard deviation of thermal emittance.

5.5 Adhesion

Determine the adhesion of the absorber coating either according to ISO 4624 (use the general method for testing both rigid and deformable substrates when selecting test assembly and use test cylinders with a diameter of 20 mm) or by means of a simpler method for assessment of adhesion (see 4.3) and proceed as specified in the relevant standard.

6 Tests for assessing the thermal stability of absorber surfaces

6.1 Principle

6.1.1 High-temperature ageing is frequently used in many technical application areas for the assessment of thermal stability of materials. A high temperature accelerates all kinds of processes, normally leading to an increased rate of degradation of materials. For a selective absorber coating composed of small metal particles, a high temperature enhances oxidation of metal decreasing mainly the absorptance of coating.

6.1.2 When installed in a single-glazed flat plate solar collector, an absorber surface is exposed to a temperature which may vary greatly; in the extreme case from −20 °C up to more than 200 °C. As a measure of the level of thermal load, the effective mean temperature, T_{eff}, during one year of service for an absorber surface is used here. It is defined by the following expression:

$$\exp\left(-\frac{E_{\mathrm{T}}}{R}T_{\mathrm{eff}}^{-1}\right)=\int_{T_{\min}}^{T_{\max}}\exp\left(-\frac{E_{\mathrm{T}}}{R}T^{-1}\right)f(T)\,\mathrm{d}T \tag{4}$$

where

$f(T)$	is yearly based frequency function for service temperature of absorber surface in solar collector, meaning the time fraction of a year when service temperature is in the interval T to T+dT;
$T_{\max}$	is the maximal service temperature of absorber surface in the solar collector in kelvin (K);
$T_{\min}$	is the minimal service temperature of absorber surface in the solar collector in kelvin (K);

E_T is the Arrhenius activation energy expressing the temperature dependence of a thermal degradation reaction of absorber surface;

R is the ideal gas law constant equal to 8,314 J/(mol·K).

6.1.3 The yearly based frequency function $f(T)$ is determined by the external climatic load acting on the solar collector and the optical properties of the solar absorber surface and the glazing.

In this recommended procedure it is assumed that the solar collector is under operating conditions for 11 months of a year and then producing tap water during daytime when the solar collector temperature exceeds 40 °C. For one month of a year, during summer, the solar collector is under stagnation conditions. From a thermal ageing point of view it is only during the sunny days when the solar collector is under stagnation that the temperature load on the solar absorber surface will result in significant thermal degradation. The reference thermal load or temperature frequency function for one year representing service conditions in this recommended procedure corresponds therefore to 30 sunny days when the solar collector is under stagnation; see Figure B.1.

The temperature load acting on the solar absorber surface depends also on the optical properties of the absorber surface and so does the maximum solar absorber surface temperature during stagnation conditions. The maximum solar absorber surface temperature is in this recommended procedure determined from the solar absorptance and the thermal emittance by use of interrelations shown in Table B.1. The reference thermal load in terms of an effective mean temperature is thereafter calculated as a function of the activation energy for thermal degradation by making use of the maximum absorber surface temperature.

NOTE If found more appropriate, another temperature frequency function may be used to represent service conditions. The new effective mean temperature corresponding to a specific activation energy may be calculated by use of Formula (4).

6.1.4 To assess the thermal stability of the absorber surface, short-term tests, enhancing thermal degradation of the absorber surface at a constant high temperature, are used. To convert the design service life of 25 years into a shortest acceptable failure time, t_R, for a constant temperature test to be executed at the temperature T_R, the following time-transformation function is used:

$$t_R = 25 \times 8\,760 \exp\left[-\frac{E_T}{R}\left(T_{\text{eff}}^{-1} - T_R^{-1}\right)\right] \tag{5}$$

where

T_{eff} is the effective mean temperature, in kelvin (K), of absorber surface defined by Formula (4).

The effective mean temperature will vary with the activation energy and so will also the shortest acceptable failure time for a specific constant temperature test.

6.1.5 To conclude whether an absorber surface is qualified or not, the results from at least two different constant temperature tests are needed unless the optical performance of solar absorber surface tested is unaffected during the first test. The qualification scheme and the conditions for the temperature tests are given in Figures B.2 to B.4 and Table B.2, respectively.

6.2 Apparatus

6.2.1 Testing chamber to be used for assessing the thermal stability of the absorber surface shall be constructed so that:

a) Constant temperature tests can be executed up to a temperature of at least 380 °C.

NOTE 1 Testing chambers with circulating air heating are recommended in favour of those based on radiative heating, because the temperature difference between the sensor and the test samples will be less because of more uniform temperature condition in testing chambers of the former type.

NOTE 2 When radiative furnaces are used, the temperature of the test samples and the temperature of the temperature sensor strongly depend on the radiation exchange with the heater and therefore also on their optical properties. It is in this case preferable to measure the temperature of the test sample for heating control.

b) The temperature is maintained at level of ±1 °C after stabilized conditions have been reached after start of test.

NOTE 3 Even a symmetrical variation around the set temperature results in a higher effective mean temperature with respect to thermal degradation.

c) The temperature in the chamber is so uniform that the variation between absorber specimens tested simultaneously is within the range of ±1 °C; see NOTE 1 and 2.

d) During cooling down of chamber after high temperature exposure, the rate of temperature decrease shall be at least 10 °C/min (from 200 °C to 100 °C). If the chamber does not meet this requirement, the test samples shall be taken out of the chamber immediately after the specified testing time has been reached; see 6.3.4.

6.2.2 Instruments for measuring of optical properties of absorber surfaces complying with the requirements as are specified in Annex A.

6.2.3 Tensile tester and test cylinders for measurement of adhesion of absorber coating in accordance with ISO 4624 as specified in 5.5. If a simpler method for assessment of adhesion is used, see 4.3, use equipment complying with the requirements given in the relevant standard for assessment of adhesion.

6.3 Procedure for execution of high temperature tests

6.3.1 Select three test samples of absorber surface with known solar absorptance and thermal emittance and qualified for testing according to 4.2.

6.3.2 Increase the temperature of the testing chamber to the specified level of test. After this temperature has been reached, place the test samples of room temperature in the testing chamber.

6.3.3 Keep the test samples at this temperature level for the specified time period of test.

6.3.4 After the specified time period of test or of interruption for measurement of the extent of degradation, decrease the temperature of the testing chamber down to room temperature. The cooling rate should be at least −10 K/min until the temperature has dropped to 40 °C or to 100 K below the testing temperature, whichever is met first.

If the testing chamber does not meet the requirement for minimum rate of cooling down as specified above, the test samples shall be taken out of the testing chamber immediately after the specified time period of test has been reached. The hot test samples shall after they have been taken out of the testing chamber be placed on a thermally insulating material to minimize damages, which may result from the thermal shock the test samples are exposed to during cooling down.

6.3.5 Determine the solar absorptance and the thermal emittance of test samples as specified in Annex A.

6.3.6 Calculate from the change in solar absorptance and thermal emittance of test samples, the value of the PC function for each panel tested by use of Formula (1). Calculate also the mean value of the PC function for the different test samples.