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TECHNICAL SPECIFICATION

colour inside

Solar thermal electric plants –
Part 3-3: Systems and components – General requirements and test methods for solar receivers

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SOLAR THERMAL ELECTRIC PLANTS –

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FOREWORD

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- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62862-3-3, which is a Technical Specification, has been prepared by IEC technical committee 117: Solar thermal electric plants.

The text of this Technical Specification is based on the following documents:

Draft TS	Report on voting
117/104/DTS	117/107/RVDTS

Full information on the voting for the approval of this Technical Specification can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62862 series, published under the general title *Solar thermal electric plants*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

The receiver is one of the most important and most sensitive components of Fresnel and parabolic trough power plants. Large mirrors are aligned to concentrate solar radiation up to 80 times along the focal line of the mirrors onto the specially coated, evacuated receivers. The generated heat is transported to a power generation unit, using a heat transfer fluid, and converted to electricity.

The quality and long-term performance stability of the receiver has a decisive influence on how effectively solar radiation can be converted into heat. For the power plant to achieve maximum efficiency, the receiver has to absorb as much solar radiation as possible and convert it into heat with minimized losses.

The solar receiver (see schematic in Figure 1) mainly consists of:

- a steel absorber tube: heat transfer fluid flows through the stainless-steel absorber tube. A high-quality absorber coating converts the solar radiation into heat and minimizes infrared heat loss at the same time;
- a glass cover tube: the cover is made from borosilicate glass and is coated with an antireflective film to increase solar transmittance;
- evacuated space (annulus) or filled with noble gas between absorber tube and glass cover tube: the vacuum between steel absorber and glass cover is essential to suppress gas heat convection;
- bellows: the bellows are necessary to compensate for different rates of heat expansion of the steel absorber and the glass cover. In contrast to the glass cover, the hot absorber expands considerably when operating.

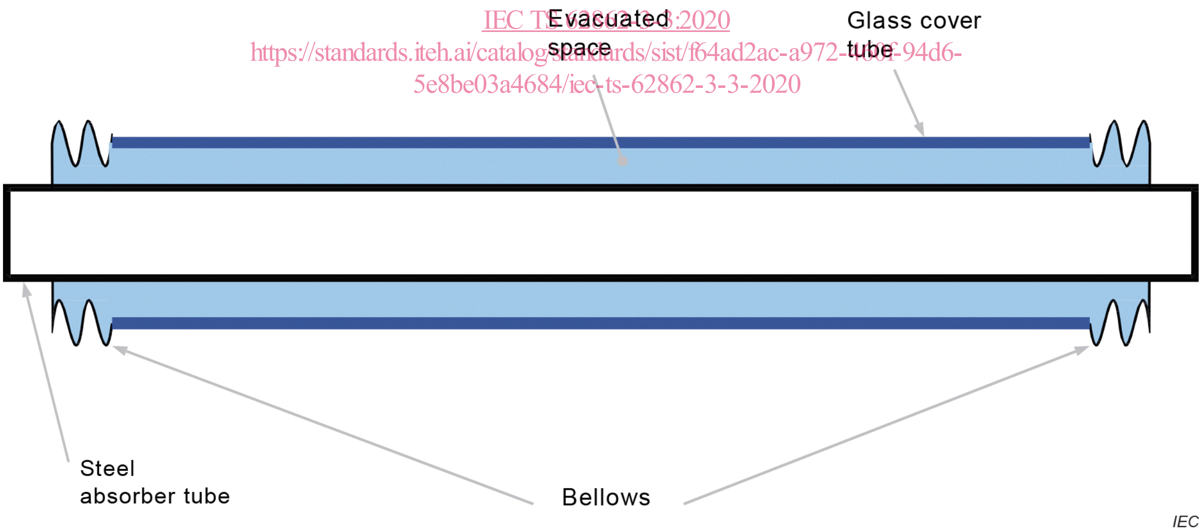

Figure 1 – Solar receiver schematic sketch

SOLAR THERMAL ELECTRIC PLANTS –

Part 3-3: Systems and components – General requirements and test methods for solar receivers

1 Scope

This document specifies the technical requirements, tests, durability and technical performance parameters of solar thermal receivers for absorbing concentrated solar radiation and transferring the heat to a fluid used in concentrated solar thermal power plants with linear-focus solar collectors. The receivers addressed consist of an absorber tube and an insulating glass envelope tube.

NOTE 1 Most of the test methods included in this document apply to solar receivers used both in solar thermal electric plants with parabolic-trough and Fresnel collectors.

This document includes the definitions of technical properties and characterization of geometry and performance parameters as well as the test methods for optical characterization, heat loss, and durability.

NOTE 2 The experience accumulated so far regarding the different test methods currently available for receiver tubes is not extensive enough to determine which test method is the best; this document describes all the different methods currently available without defining one recommended method.

For the sake of clarity, it is stated here that the thermal loss tests described in this document do not deliver the thermal loss of the receiver tubes when they are installed in commercial solar fields.

Thermal losses obtained by indoor testing on a single receiver are significantly lower than the thermal losses in outdoor, real operating conditions at commercial solar fields. However, the indoor test procedures described in this document are suitable for receiver tube performance comparison.

The thermal losses taken into account for solar field design are obtained by testing complete collectors operating under real solar conditions.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC TS 62862-1-1, *Solar thermal electric plants – Part 1-1: Terminology*

ISO 6270-2:2017, *Paints and varnishes – Determination of resistance to humidity – Part 2: Condensation (in-cabinet exposure with heated water reservoir)*

ISO 9806:2017, *Solar energy – Solar thermal collectors – Test methods*

ISO 9488:1999, *Solar energy – Vocabulary*

MIL-E-12397 – *Eraser, Rubber-Pumice (for testing coated optical elements)*

ASTM G173 – 03 – *Standard Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface*

3 Terms, definitions, symbols and units

For the purposes of this document, the terms, definitions, symbols and units contained in ISO 9488 and IEC 62862-1-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Performance test of the receiver

4.1 General

As receivers are one of the most important components in the solar field, they have a big impact on the performance of the entire solar field. In order to be able to best simulate the lifetime performance of the receiver as well as that of the solar field, it is crucial to perform tests that characterize the receiver and its performance.

4.2 Identification and geometry

The receiver usually has a brand name for the product and is also defined by the outer diameter of the stainless-steel tube. Another important identifier/parameter is the length of the receiver, which may vary depending on the trough for which it is designed. Additional parameters such as absorptance, emittance, transmittance, vacuum pressure, stainless-steel material, design temperature and pressure and the Heat Transfer Fluid for which it is designed, can be obtained from the manufacturer. These parameters/characteristics should be noted as part of the report for the receiver being tested.

4.3 Manufacturer's instructions

In addition to the parameters in 4.2, the manufacturer may have additional instructions for the use/preparation of the receiver or parts thereof for testing, for example, the cleaning of samples prior to carrying out optical measurements. These instructions shall be noted as part of the test procedure in case they have an effect on the results.

4.4 Calibration of testing instrumentation

Unless otherwise indicated by the manufacturer of the testing device, all instruments used should be calibrated at least once a year. In the event that a device is used that requires special calibration (i.e. spectrophotometer requiring calibration using a "golden sample"), this should be noted in the report including the date of calibration and the specimen used.

4.5 Heat loss test

4.5.1 General

NOTE In 2016, a round robin test was carried out within the European project STAGE-STE (European Union Seventh Framework Program FP7 (2007-2013) under grant agreement ID 609837) with five different tubes from different manufacturers. From this round robin, the heat loss testing results showed standard deviations in the order of 6 % to 12 % for most temperatures and receivers (see [1][1]).

[1] Numbers in square brackets refer to the Bibliography.

These differences should be considered when comparing results by different laboratories using different methodologies. It is recommended when trying to compare receivers from different manufacturers to test all receivers in the same method at the same institute, to get comparable results.

For the thermal loss test, one of the following methods shall be used (both are described below):

- resistance heating method;
- Joule effect method.

4.5.2 Objective

The purpose of this test is the thermal characterization of a solar receiver tube including determination of the heat loss curve and calculation of thermal emittance (optional) based on test data.

The application of this test is associated with the needs of solar thermal power plant projects using parabolic-trough technology and, by analogy, also Fresnel technology. It is applicable to solar receiver tubes forming part of a parabolic-trough collector or a Fresnel collector.

4.5.3 Receiver tube setup and location

4.5.3.1 General

The way in which the receiver tube is set up on the test bench has a determining influence on the heat loss test results, so it is therefore recommended that the test bench is set up as described in the following subclauses of 4.5.3. The tests shall be performed indoors to minimize any possible environmental influence on the test samples. In addition, the space around the receiver, equal to at least 50 cm on all sides, should be free from big obstacles to avoid limiting natural air circulation.

In the event that the test is carried out under vacuum conditions, the surroundings are not important as air circulation is negligible.

The general principle of measurement is based on the conversion of electricity into heat under stationary conditions. Under these conditions, the heat loss is equivalent to the power necessary to maintain the receiver at a constant temperature. Determination of the power required at different temperatures leads to the heat loss curve characteristic of the receiver test sample.

There are different methods for heating the receiver. For example, by Joule effect, by electrical heated elements or by IR resistance attached to a copper tube inserted inside the absorber tube (see example in [2]).

4.5.3.2 Receiver tube setup and initial inspection

The receiver tube to be tested shall be placed horizontally in the test support frame holders.

The absorber tube shall be visually inspected, and any damage or modification observed shall be recorded in the test report.

4.5.3.3 Temperature measurements

The receiver tube temperature shall be measured with temperature sensors touching the absorber from the inside in at least six positions along it, arranged symmetrically from the centre, with a gap of no more than 1 m between sensors. Additional sensors shall be located near the ends of the tube and be in contact with the tube, in order to control gradients towards the ends. Three sensors are recommended for measuring the glass surface temperature.

The ambient temperature sensor shall be placed not more than 2 m from the sample, in a location where it is not affected by hot spots or air currents. The positions of the sensors shall be recorded in the report.

The temperature sensors shall be calibrated according to the temperature range to be tested.

The expanded uncertainties of the average temperatures of each sensor shall be less than:

- ±2 °C for the absorber tube;
- ±2 °C for the glass envelope tube;
- ±1 °C for ambient or surrounding air.

Uncertainty calculations are determined in accordance with ISO 9806:2017, Annex D.

The contact shall be suitable to ensure correct measurement. Correction methods for compensating the influence temperature gradients near the sensors might be applicable.

Pressing temperature sensors on the absorber or glass often leads to inadequate measurements as temperature sensors are influenced by air temperature and radiation temperature in the annulus and heat conduction along the thermocouple wires. Reference measurements can be used to ensure the validity of the measurement setup or to correct the measurements, see Annex B. The temperature corrections, if done, shall be noted in the test report.

4.5.3.4 Power measurements

The measurement equipment for electric heating power shall have an accuracy of at least 3 % of the actual reading.

4.5.3.5 Data acquisition frequency

Power sensors used in the test shall be calibrated. Data recording frequency shall be no less than 1 recording per 20 s and the minimum number of records shall ensure the statistical representativeness of the test.

4.5.4 Inspection

When the test has finished, the receiver tube shall be inspected and note taken of any change observed. Changes observed shall be recorded in the test report; photographs can be added.

4.5.5 Test methodology – Resistance heating method

4.5.5.1 Measurements

At least the following data shall be measured.

Before the test:

- the length of the metal receiver absorber tube measured at ambient temperature using a measuring instrument (e.g. measuring tape) with an uncertainty of 1 mm. The instrument should be inserted into the tube and measured from one end to the other;
- diameter (inner and outer) of the absorber tube measured at ambient temperature using a caliper with an accuracy of at least 1/10 mm;
- position of temperature sensors using a measuring instrument (e.g. measuring tape) with an uncertainty of at least 1 mm, with reference to a specific end/position on the absorber tube.

During the test:

- temperatures of the absorber tube;
- temperatures of the glass envelope tube (optional);
- temperature of the surrounding air;
- electrical power supplied by the resistance heaters or any other element used.

4.5.5.2 Procedure and test time

The measurement is performed at a steady state of stable absorber temperature and heating power. Therefore, the following arithmetic means of evaluation of the measured quantities over a longer evaluation period, which will also be called measurement point, are used.

Minimum evaluation periods are given in Table 1.

Table 1 – Evaluation periods

Absorber tube temperature in °C	Minimum evaluation period in min
100 to 200	240
200 to 300	120
300 to 400	60
400 to 500	30
> 500	15

Table 2 shows the criteria for stability and homogeneity that shall be met for the duration of the evaluation period.

Table 2 – Stability requirements

Parameter to be monitored	Stability requirement
Absorber tube temperatures	±0,5 °C
Absorber tube temperature homogeneity S_{TH}	< 0,04 $T_{\text{abs,mean,°C}}$
Heat loss (Equation (2))	±1 %
Ambient temperature	20 °C ± 10 °C

Criteria in Table 2 refer to simple moving means (without weights) over 1 min for the quantities of interest. The criterion for absorber tube temperatures refers to the temporal stability for each temperature sensor.

Absorber tube temperature homogeneity S_{TH} (t) at time, t, is defined as the difference of the highest and smallest measured temperature at t divided by the mean temperature:

$$S_{\text{TH}} = \frac{T_{\text{abs,max}} - T_{\text{abs,min}}}{T_{\text{abs,mean}}} \tag{1}$$

The maximum difference measured during one measurement between the different absorber temperatures along the tube is important as it may indicate the uniformity of the coating.

The value of uniformity of S_{TH} should be mentioned in the report. In addition, if during the measurement it was found that S_{TH} > 2 % a warning should be mentioned in the report.

- Method to achieve steady state:

PI or PID controllers can be used to control electric power input to reach target temperature and a steady state. Steady state is achieved when heater set points do not change and the centre-of-glass and absorber temperatures vary by less than 0,5 °C for a period of at least 15 min.

- This criterion of uniformity shall be followed throughout the steady-state period.

Once the desired absorber tube test temperature is reached and the adiabaticity of the process at the ends of the tube is verified, measurements for steady-state periods shall be performed. A measurement steady-state period shall have a duration of 15 min during which the stability conditions listed in Table 2 shall be verified. Before each steady-state period, a 30-min period shall verify the same stability conditions listed in Table 2.

4.5.5.3 Heat loss (HL) calculations

Calculations shall be done using measurement point means.

The uncertainty of measurement shall be calculated in accordance with ISO 9806:2017, Annex D.

The coefficient of loss in a receiver tube is defined as:

$$HL = \frac{\sum_i Pow_i + HL_{\text{ends}}}{L_{\text{HCE}(25\,°\text{C})}} \tag{2}$$

where

HL is the heat loss of the tube [W/m];

Pow_i is the electrical power consumed by heating element i [W];

HL_{ends} is the heat loss at the tube ends [W].

Example of a test bench with a copper tube as heater type:

For this type of test bench, only the ends are insulated; the heat loss of the ends should be calculated, for example, in the following way:

$$HL_{\text{ends}} = \frac{kA}{\Delta x}\left(T_1 - T_2\right) + \frac{kA}{\Delta x}\left(T_N - T_{N-1}\right) \tag{3}$$

where

$T_{1/2/N/N\text{-}1}$ indicates the temperatures measured by sensors at the ends [°C] assuming N sensors. In the case of a test bench based on electrical heating elements, the sensors at the ends of the copper tube would be taken;

k is the coefficient of conductivity of copper [W/m °C];

A is the surface area of copper tube (heater) [m^2];

Δx is the distance between sensors at ends [m];

$L_{\text{HCE}(25\,°\text{C})}$ is the length of receiver tube at ambient temperature (25 °C ± 10 °C) [m]. The length of the receiver tube aperture shall be measured.

The mean temperature of the absorber is calculated by weighting the distance that each sensor covers along the absorber tube: