Solar Facilities for the European Research Area

SEVENTH FRAMEWORK PROGRAMME

Grant Agreement No. 228296

SFERA

Solar Facilities for the European Research Area

SEVENTH FRAMEWORK PROGRAMME
Capacities Specific Programme
Research Infrastructures

Integrating Activity - Combination of Collaborative Project and Coordination and Support Action

R12.1 Report on parameters definition for consideration in components evaluation

Due date of deliverable: month 6
Actual submission date: Month 24

Organisation name of lead contractor for this deliverable: CNRS

Table of Contents

Table of Contents 2
Introduction 4
Objectives and methodology 4
Parameters concerning Radiation and Meteorological Data 5
Revision History (Meteorological Parameters) 5
Parameter: Direct Normal Irradiance 5
Parameter: Diffuse Horizontal Irradiance 5
Parameter: Global Horizontal Irradiance 6
Parameter: Downward Longwave Irradiance 7
Parameter: Circumsolar ratio 7
Parameter: Sunshape 8
Parameter: Air Temperature 9
Parameter: Relative Humidity 10
Parameter: Pressure 10
Parameter: Wind Speed 10
Parameter: Wind direction 11
Parameters concerning Concentrator and Facets 12
Revision History 12
Description 12
Component: Concentrator; Parameter: Geometric accuracy 12
Component: Concentrator; Parameter: Stability 12
Component: Concentrator; Parameter: Stiffness 12
Component: Concentrator; Parameter: Tracking accuracy 12
Sub-component: facet; Parameter: Effective solar reflectance 13
Sub-component: facet; Parameter: Shape accuracy 13
Sub-component: facet; Parameter: Stability 14
Sub-component: facet; Parameter: Stiffness 14
Sub-component: facet; Parameter: Nominal intercept factor 14
Sub-component: facet; Parameter: Nominal shooting error 14
Parameters concerning Receiver 15
Revision History 15
Parameter: Receiver Efficiency 15
Parameter: Thermal Inertia 15
Parameter: Maximum Operating Temperature 16
Parameter: Thermal Shock Resistance 16
Parameter: Corrosion resistance 17
Parameter: Density 18
Parameter: Thermal Conductivity 18
Parameter: Specific Heat Capacity 19
Parameter: Thermal Expansion Coefficient 19
Parameter: Young Modulus 20
Parameter: Poisson ratio 20
Parameter: Yield strength 21
Parameter: Ultimate Tensile Strength 21
Parameter: Absorbance 22
Parameter: Reflectance 22

Parameter: Emissivity 23
Parameter: Window transmittance 23
Parameter: Heat Transfer Coefficient 24
Parameter: Exchange Area 25
Parameters concerning heat transfer fluids 26
Revision History 26
Parameter: Density 26
Parameter: Thermal Conductivity 26
Parameter: Heat Capacity 26
Parameter: Thermal Diffusivity 27
Parameter: Thermal Expansion Coefficient 27
Parameter: Enthalpy of vaporization 27
Parameter: Enthalpy of Fusion 27
Parameter: Fire Bearing Point (Pyrophority) 28
Parameter: Flammability 28
Parameter: Auto-ignition temperature 28
Parameter: Vapour Pressure 28
Parameter: Boiling point (at normal conditions) 29
Parameter: Viscosity 29
Parameter: Speed of sound in fluids 29
Parameter: Impurities/degradation components 29
Parameter: Thermal Conductivity 30
Parameter: Melting point 30
Parameter: Freezing point 30
Parameter: Maximum working temperature 30
Parameters concerning the Power Conversion Unit 31

Introduction

Europe is a leader in research and development of Concentrated Solar Power Technology. Most of the large R&D infrastructures are European and our industry is leading the way in its commercial deployment. Currently all facilities use their own procedures to perform tests and experiments under concentrated sunlight and have developed their own devices to measure flux and temperature as the most relevant and complex data in these installations

Work package 12 of the joint research part within the EU-funded project 'Solar Facilities for the European Research Area (SFERA)' is aimed at improving the quality and service of the existing infrastructures and to extend their services taking benefit form the specific competences and experiences of the individual labs to jointly achieve a common level of high scientific quality and service through this synergistic approach. The partners cooperate to establish common guidelines how to perform testing, develop and exchange best-practice approaches.

Objectives and methodology

To establish guidelines for measurement and evaluation procedures a systematic approach was chosen. In a first step a list of parameters were collected that are important for the evaluation of components for concentrated solar power systems under 'scientific conditions' in the participating organisations. This list should later be taken into account when the guidelines will be elaborated.

A CSP system consists of the following components: concentrator, receiver and power conversion unit (PCU). For each of these components a group of important parameters was defined. The general input parameters are the ambient conditions which have to be defined in a separate part. Since heat transfer fluids (HTF) have an important role in all CSP systems a group of parameters was defined that cover the characteristics of the HTFs. CPU parameters were considered too specific for each system and it was decided to establish just a list of very general parameters for this topic.

The current report was prepared by a group of scientist from the following organisations:

- CIEMAT
- CNRS
- DLR
- ENEA
- WEIZMANN

Where possible the document and definitions were reviewed by colleagues from different departments to make sure a wide acceptance of the contents. Although this report has to be delivered as a finished version a later revision of the list is very likely and refinement may be desirable when new parameters are necessary for the final purpose.

Parameters concerning Radiation and Meteorological Data

Revision History (Meteorological Parameters)

2011/03 Edited by DLR
Stefan Wilbert, Stefan.wilbert@dlr.de
Wolfgang Reinalter, wolfgang.reinalter@dlr.de

2011/04 Revised by ENEA
Dr. Euro Cogliani, euro.cogliani@enea.it
Dr. Francesco Spinelli, francesco.spinelli@enea.it

Parameter: Direct Normal Irradiance

Abbr.: DNI

Description / Definition

Irradiance caused by solar radiation received from a small solid angle centred on the sun's disc, on a plane perpendicular to the vector to the sun's centre.

Unit: W/m^2

Importance

Direct Normal Irradiance is the irradiance that is used with CSP.

Standards and references

WMO (2008). "Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, Seventh edition." (Please check everywhere)
ISO-9059 (1990). Solar energy - Calibration of field pyrheliometers by comparison to a reference pyrheliometer.
ISO-9060 (1990). Solar energy - Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.

Comments

The penumbra function of the instrument has to be known.

Parameter: Diffuse Horizontal Irradiance

Abbr.: DfHI

(to avoid confusion with "Direct")

Description / Definition

Irradiance caused by solar radiation from a solid angle of 2π sterad above a horizontally levelled surface excluding a small (how much?) solid angle centred on the sun's disc.

Unit: W/m²

Importance

Can be used to calculate DNI when GHI is also measured. If a second DNI measurement is available this can be used as a quality control of the measurements.

Standards and references

WMO (2008). „Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, Seventh edition."
ISO-9059 (1990). Solar energy - Calibration of field pyrheliometers by comparison to a reference pyrheliometer.
ISO-9060 (1990). Solar energy - Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.
McArthur, L. J. B. (2005). BASELINE SURFACE RADIATION NETWORK (BSRN) Operations Manual Version 2.1. WCRP-121 WMO/TD-No. 1274 WORLD CLIMATE RESEARCH PROGRAMME.
Stoffel, T., D. Renne, et al. (2010). Concentrating Solar Power: Best Practices Handbook for the Collection and Use of Solar Resource Data (CSP), National Renewable Energy Laboratory (NREL), Golden, CO.

Comments

N/A

Parameter: Global Horizontal Irradiance

Abbr.: GHI

Description / Definition

Irradiance caused by solar radiation from a solid angle of 2π sr above a horizontally levelled surface.

Unit: W/m²

Importance

Can be used to calculate DNI when DHI is also measured. If a second DNI measurement is available this can be used as a quality check of the measurements.
GHI has to be included for efficiency measurements when the receiver is exposed also to global horizontal radiation (please explain better).

Standards and references

WMO (2008). „Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, Seventh edition."
ISO-9060 (1990). Solar energy - Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.
ISO9846 Solar energy – Calibration of a pyranometer using a pyrheliometer
ISO9847 Solar energy – Calibration of field pyranometers by comparison to a reference pyranometer

McArthur, L. J. B. (2005). BASELINE SURFACE RADIATION NETWORK (BSRN) Operations Manual Version 2.1. WCRP-121 WMO/TD-No. 1274 WORLD CLIMATE RESEARCH PROGRAMME.
Stoffel, T., D. Renne, et al. (2010). Concentrating Solar Power: Best Practices Handbook for the Collection and Use of Solar Resource Data (CSP), National Renewable Energy Laboratory (NREL), Golden, CO.

Comments

N/A

Parameter: Downward Longwave Irradiance

Abbr.: IR_d

Description / Definition

Irradiance caused by long-wave (~3000nm – ~100000nm) radiation from a solid angle of 2π sr above a horizontally levelled surface.

Unit: W/m²

Importance

Correction of systematic errors of GHI, DHI and DNI measurements.
The exchange of radiation of hot elements in the CSP system with the ambient depends on the incident long-wave radiation.

Standards and references

WMO (2008). „Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, Seventh edition."
McArthur, L. J. B. (2005). BASELINE SURFACE RADIATION NETWORK (BSRN) Operations Manual Version 2.1. WCRP-121 WMO/TD-No. 1274 WORLD CLIMATE RESEARCH PROGRAMME.

Comments

N/A

Parameter: Circumsolar ratio

Abbr.: CSR

Description / Definition

Circumsolar radiation is radiation coming from a region close to the solar disk (~0.266° - ~5°). It can be described quantitatively as the solar radiance as a function of the angular distance from the sun. When the disk radiance profile is included this function is called sunshape.

Unit: %

Importance

Circumsolar radiation is only partially used by focusing collectors and nearly completely detected by pyrheliometers following ISO 9060. In the evaluation of the optical efficiency the sunshape has to be included. As the sunshape is highly dependent on the clearness of the atmosphere and variable due to the presence of clouds and aerosols the sunshape has to be documented for precise CSP tests.

Standards and references:

WMO (2008). „Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, Seventh edition."
ISO-9060 (1990). Solar energy - Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.
ISO9846 Solar energy – Calibration of a pyranometer using a pyrheliometer
ISO9847 Solar energy – Calibration of field pyranometers by comparison to a reference pyranometer
McArthur, L. J. B. (2005). BASELINE SURFACE RADIATION NETWORK (BSRN) Operations Manual Version 2.1. WCRP-121 WMO/TD-No. 1274 WORLD CLIMATE RESEARCH PROGRAMME.
Stoffel, T., D. Renne, et al. (2010). Concentrating Solar Power: Best Practices Handbook for the Collection and Use of Solar Resource Data (CSP), National Renewable Energy Laboratory (NREL), Golden, CO.
Buie, D. and A. Monger (2004). "The effect of circumsolar radiation on a solar concentrating system." Solar Energy **76**(1-3): 181-185.
Neumann, A. and B. Von Der Au (1997). "Sunshape Measurements at the DLR Solar Furnace Site in Cologne, Germany." SOLAR ENGINEERING: 163-170.

Comments

N/A

Parameter: Sunshape

Abbr.: SSH

Description / Definition

The circumsolar ratio (CSR) is defined as the normal irradiance caused by circumsolar radiation divided by the normal irradiance caused by circumsolar radiation and the radiation coming from the solar disk itself. The CSR characterizes the sunshape.

Unit: W/(m²sr)

Importance

Circumsolar radiation is only partially used by focusing collectors and nearly completely detected by pyrheliometers following ISO 9060. In the evaluation of the optical efficiency the sunshape has to be included. As the sunshape is highly variable due to the presence of clouds and aerosols the sunshape has to be documented for precise CSP tests.

Standards and references

WMO (2008). „Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, Seventh edition."
ISO-9060 (1990). Solar energy - Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.
ISO9846 Solar energy – Calibration of a pyranometer using a pyrheliometer
ISO9847 Solar energy – Calibration of field pyranometers by comparison to a reference pyranometer
McArthur, L. J. B. (2005). BASELINE SURFACE RADIATION NETWORK (BSRN) Operations Manual Version 2.1. WCRP-121 WMO/TD-No. 1274 WORLD CLIMATE RESEARCH PROGRAMME.
Stoffel, T., D. Renne, et al. (2010). Concentrating Solar Power: Best Practices Handbook for the Collection and Use of Solar Resource Data (CSP), National Renewable Energy Laboratory (NREL), Golden, CO.
Buie, D. and A. Monger (2004). "The effect of circumsolar radiation on a solar concentrating system." Solar Energy **76**(1-3): 181-185.
Neumann, A. and B. Von Der Au (1997). "Sunshape Measurements at the DLR Solar Furnace Site in Cologne, Germany." SOLAR ENGINEERING: 163-170.

Comments

N/A

Parameter: Air Temperature

Abbr.: T_a

Description / Definition

Temperature of the air.

Unit: °C

Importance

The air temperature is an important factor for the calculation of the receiver efficiency, system thermal losses and power cycle efficiency (e.g. gas turbine).

Standards and references

WMO (2008). „Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, Seventh edition.

Comments

N/A

Parameter: Relative Humidity

Abbr.: RH

Description / Definition

The ratio in per cent of the observed vapour pressure to the saturation vapour pressure with respect to water at the same temperature and pressure (WMO, 2008).

Unit: %

Importance

Relative humidity is a relevant parameter for calculating the atmospheric attenuation, power block cooling and receiver efficiency, depending on the technology.

Standards and references

WMO (2008). „Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, Seventh edition."

Comments

N/A

Parameter: Pressure

Abbr.: p

Description / Definition

The atmospheric pressure on a given surface is the force per unit area due to the weight of the above atmosphere (WMO, 2008).

Unit: Pa

Importance

The atmospheric pressure is of importance for the receiver and power block efficiency (depending on the technology) and for cooling.

Standards and references

WMO (2008). „Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, Seventh edition."

Comments

N/A

Parameter: Wind Speed

Abbr.: v_W

Description / Definition

Absolute amount of the projection of the wind vector in a horizontal plane.

Unit: m/s

Importance

Wind speed and wind direction are important for the evaluation of both the optical efficiency of the collector (deformation), the receiver efficiency (convection) and the operation of the collectors (at a speed above certain allowable level the collectors are stowed).

Standards and references

WMO (2008). „Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, Seventh edition."

Comments

Wind gusts should be measured, too. This is the maximum of the wind speed in a specified time interval.

Parameter: Wind direction

Abbr.: dw

Description / Definition

Wind direction is reported by the direction from which it originates.

Unit: °N

Importance

Wind speed and wind direction are important for the evaluation of both the optical efficiency of the collector (deformation), and the receiver efficiency (convection).

Standards and references

WMO (2008). „Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, Seventh edition."

Comments

N/A

Parameters concerning Concentrator and Facets

Revision History

2011/03 Edited by ENEA
Marco Montecchi, marco.montecchi@enea.it

Description

To describe concentrator systems the following describing parameters were proposed

Component: Concentrator

Typology: dish / linear Fresnel /parabolic-trough /tower.
Technology: main characteristics of the adopted manufacturing technology.
Dimension: physical and nominal-area intercepting solar-radiation.
Tracking system: information on the drive mechanism system.

Sub-components: facets

Target-shape: flat / parabolic trough / parabolic / spherical / …
Technology: main characteristics of the adopted manufacturing technology (as an example, back-silvered glass, 4 mm thick).
Dimension: physical and nominal-area intercepting solar-radiation.
Coupling system: how facets are coupled to the supporting structure.

Component: Concentrator; Parameter: Geometric accuracy

Description / Definition:

Deviations from the projected values of the coordinates of the points where facets and, except for the Tower typology, receiver are located.

Component: Concentrator; Parameter: Stability

Description / Definition:

Ability to maintain constant the “geometric accuracy” along ageing and thermal excursions.

Component: Concentrator; Parameter: Stiffness

Description / Definition:

Ability to maintain constant the “geometric accuracy” along Sun tracking and under wind solicitude.

Component: Concentrator; Parameter: Tracking accuracy

Description / Definition:

Angular deviations from the nominal aiming.

Sub-component: facet; Parameter: Effective solar reflectance

Description / Definition:

Reflectance is the fraction of incident electromagnetic power that is reflected at an interface. In general it must be treated as a directional property that is a function of the incident direction, the reflected direction, and the incident wavelength.

Considering the reflected direction, reflectance is divided in the three components: *specular, diffuse* and *hemispherical*; the latter being the sum of the others two.

The *spectral reflectance* is the reflectance resolved for the radiation wavelength.

Solar reflectance is the average over the solar spectrum of the spectral reflectance.

The *effective solar reflectance* is the portion of the solar reflectance effectively reflected towards the receiver and intercepted by it.

Standards and references

ISO 5740. Road vehicles -- Rear view mirrors -- Test method for determining reflectance
ISO 6719. Anodizing of aluminium and its alloys -- Measurement of reflectance characteristics of aluminium surfaces using integrating-sphere instruments
ISO 7668. Anodizing of aluminium and its alloys -- Measurement of specular reflectance and specular gloss of anodic oxidation coatings at angles of 20 degrees, 45 degrees, 60 degrees or 85 degrees
ISO 7759. Anodizing of aluminium and its alloys -- Measurement of reflectance characteristics of aluminium surfaces using a goniophotometer or an abridged goniophotometer
ISO 9060. Solar energy -- Specification and classification of instruments for measuring hemispherical solar and direct solar radiation
ISO 9845-1. Solar energy -- Reference solar spectral irradiance at the ground at different receiving conditions -- Part 1: Direct normal and hemispherical solar irradiance for air mass 1.5
ISO 15368. Optics and optical instruments -- Measurement of reflectance of plane surfaces and transmittance of plane parallel elements

Sub-component: facet; Parameter: Shape accuracy

Description / Definition:

Deviations from the target shape in terms of

1. z
2. arctangent of $\partial z/\partial x$ and $\partial z/\partial y$

where the XYZ Cartesian reference is set with the z axis parallel to the optical axis of the concentrator; the others are parallel/orthogonal to other relevant direction if there is any.

Sub-component: facet; Parameter: Stability

Description / Definition:

Ability to maintain constant the “shape accuracy” and the “nominal intercept factor” along ageing and thermal excursions.

Sub-component: facet; Parameter: Stiffness

Description / Definition:

Ability to maintain constant the “shape accuracy” and the “nominal intercept factor” under gravity and wind solicitude, made safe the constancy of the fixing points.

Sub-component: facet; Parameter: Nominal intercept factor

Abbr.: IF

Description / Definition:

Ratio of the rays reflected towards the receiver and geometrically captured by it. The directions of the hitting rays are distributed like the solar radiation. The facet is assumed installed by means of its fixing points on a perfect supporting structure which is tracking the Sun. In the case of multi-concentrator system, all the other parts are assumed perfectly shaped and positioned.

Sub-component: facet; Parameter: Nominal shooting error

Abbr.:

Description / Definition:

Distance between reflected ray and target. The facet is assumed installed by means of its fixing points on a perfect supporting structure which is tracking the Sun. In the case of multi-concentrator system, all the others parts are assumed perfectly shaped and positioned.

Parameters concerning Receiver

Revision History

2011/04 Edited by CNRS
Emmanuel Guillot, emmanuel.guillot@promes.cnrs.fr

2011/05 Revised by ENEA
Antonio De Luca, antonio.deluca@enea.it

Parameter: Receiver Efficiency

Abbr.: η

Component: Receiver

Description / Definition:

The receiver efficiency is the ratio between the solar power provided at the surface or the entry of the solar receiver and the thermal power actually provided to the process.
The solar receiver, with or without cavity, lose power to the environment by radiation and natural or forced convection.

Unit: % of the concentrated solar power

Importance:

The receiver efficiency ratio denotes the amount of losses between the available solar power and the actual power delivered to the process.
The higher the efficiency is, the smaller the optical system can be and thus the lower the cost for the land and optical system.

Standards and references

N/D

Parameter: Thermal Inertia

Abbr.:

Component: Receiver

Description / Definition:

Thermal inertia of the receiver defines the capacity to reduce and delay the variation with time of the temperature distribution of the absorber tube, due to the variation of the direct solar radiation. It's a function of temperature, thermal capacity and thermal conductivity of the materials and mass flow rate of the heat transfer fluid.
In the case of the tower this merit is related to the entire cavity enclosure.

Unit:

Importance:

To perform a better evaluation of the energy efficiency of the solar receiver, it is necessary to take into account its thermal inertia, as a function of the variability of the direct solar radiation due to the passage of clouds.

Standards and references

N/D

Comments

The evaluation of the thermal inertia should be performed on an experimental facility as a function of temperature and mass flow rate of the heat transfer fluid trough the absorber tube.

Parameter: Maximum Operating Temperature

Abbr.: T_{max}

Component: Receiver

Description / Definition:

Maximum temperature of the receiver, theoretically localized in the middle of the irradiated zone of the absorber tube

Unit: °C

Importance:

This parameter defines the minimum value of the mass flow rate of the solar receiver in operation, for avoiding the fast aging of the absorber coating

Standards and references

ASTM specification for high temperature of steel, fittings and valves

Parameter: Thermal Shock Resistance

Abbr.:

Component: Receiver

Description / Definition:

Thermal shock resistance of receiver tubes for parabolic troughs is related to the capacity of maintaining the vacuum when the ambient temperature become very low, with possibility of formation of ice on the glass tubes (in winter season during the night).

Unit: N/A

Importance:

For evacuated solar receiver tubes thermal shock resistance can be important for glass tubes (borosilicate glass) and glass-to-metal seals.
In normal operation of a parabolic trough plant (with diathermic oil or molten salt), thermal shock for the steel tube is not possible.

The thermal shock parameter is defined as: $R = \frac{K\sigma_s(1-\nu)}{\alpha E}$

K: Thermal conductivity
σ_s: Tensile strength
ν: Poisson coefficient
α: Thermal expansion coefficient
E: Young's modulus

Higher values of αE and low value of K, reduce the capacity of thermal shock resistance of the glass

Standards and references

ASTM specification for standard test methods

Parameter: Corrosion resistance

Abbr.:

Component: Receiver

Description / Definition:

The corrosion resistance of evacuated solar receiver tubes could be defined as the resistance ability of the metallic components to chemical attack and maintaining the vacuum for the expected operating time (about 25 years)

Unit: Corrosion rate ($\mu m \cdot year^{-1}$)

Importance:

Very important for the operation reliability of the solar receiver

Standards and references

ASTM Specification for standard test methods

Parameter: Density

Abbr.: ρ

Component: Receiver

Description / Definition:

Mass per unit of material volume

Unit: kg m^{-3}

Importance

N/D

Standards and references

ASTM Specification for standard test methods

Parameter: Thermal Conductivity

Abbr.: λ

Component: Receiver

Description / Definition:

Quantity of heat transferred per unit of time, unit of surface and unit of temperature gradient

Unit: W m^{-1} $°C^{-1}$

Importance:

Higher conductivity of the steel improve the heat exchange coefficient between the steel tube and the heat transfer fluid

Standards and references

ASTM specification for standard test methods
http://en.wikipedia.org/wiki/Thermal_conductivity

Comments

The thermal conductivity has be determined as a function of temperature

Parameter: Specific Heat Capacity

Abbr.: C

Component: Receiver

Description / Definition:

For each component of the receiver is defined as the amount of the heat required for changing of 1 °C the temperature of the unit of mass

Unit: J kg^{-1} °C^{-1}

Importance:

The specific heat is related to the thermal inertia of the steel tube and to the quantity of thermal energy that can be stored for smoothing the variation of the concentrated solar radiation, but also parasitic heat load on the daily performance.

Standards and references

ASTM specification for standard test methods
http://en.wikipedia.org/wiki/Specific_heat_capacity

Comments

The specific heat of the materials has to be determined as a function of the temperature

Parameter: Thermal Expansion Coefficient

Abbr.:

Component: Receiver

Description / Definition:

Variation of the material's size due to the variation of temperature

Unit: °C^{-1}

Importance:

The coefficient of thermal expansion is directly proportional to the strain produced by differences of temperature within the material

Standards and references

ASTM specification for standard test methods
http://en.wikipedia.org/wiki/Thermal_expansion

Comments

The thermal expansion coefficient has to be determined as a function of temperature

Parameter: Young Modulus

Abbr.: E

Component: Receiver

Description / Definition:

The Young Modulus is the modulus of elasticity of the materials. It's the coefficient of proportionality between stress and strain, characteristic of the elastic phase of the materials. The Young Modulus defines the structures stiffness (steel tube, glass tube, bellows, etc.), which is the capacity of those structures to resist to deformations.

Unit: Pa

Importance:

It's the proportional coefficient for evaluating the stress induced by imposed deformations and not uniform distribution of the temperature within the materials

Standards and references

ASTM specification for standard test methods
http://en.wikipedia.org/wiki/Young%27s_modulus

Comments

The Young modulus has to be determined as a function of.the temperature

Parameter: Poisson ratio

Abbr.: υ

Component: Receiver

Description / Definition:

Poisson coefficient describes the strain of the materials in direction perpendicular to the application of the load

Unit: dimensionless

Importance:

For isotropic materials defines the relationship between the Shear Modulus (G) and the Young Modulus (E): $G = \frac{E}{2(1+\nu)}$

Standards and references

ASTM specification for standard test methods
http://en.wikipedia.org/wiki/Poisson%27s_ratio

Comments
N/D

Parameter: Yield strength

Abbr.:

Component: absorber tube

Description / Definition:
Maximum stress applied to prevent permanent deformation of the materials. The yield strength is defined as the tensile stress for inducing 0.2% of permanent strain

Unit: Pa

Importance:
In normal operating conditions the stress of the steel tube (due to fluid pressure, temperature distribution, constraints), must be always lower than the yield strength.
The Code ASME B31.1 and the European Standard EN 10217-7, give all information about the maximum allowable stress and yield strength of the Austenitic stainless steel (good corrosion resistance at high temperature), useful for designing the absorber stainless steel tube of parabolic troughs.
In accident situations (accidental closure of a valve, high difference of temperature between the irradiated and shaded zones of the absorber tube, block of the fluid circulation pump), there must be safeguards for avoiding that the maximum stress in the steel piping exceeds the yield strength.

Standards and references
ASTM specification for standard test methods
http://en.wikipedia.org/wiki/Yield_strength

Parameter: Ultimate Tensile Strength

Abbr.:

Component: Receiver

Description / Definition:
Maximum stress leading to the destruction of the receiver.

Unit: Pa

Importance:
The ASME code B31.1 provides the maximum allowable stress values to use for the design of the steel tube, but in any case should also be carried out tensile tests on standard samples of steel to be used for manufacturing the absorber tube.

For parabolic trough receivers is very important the ultimate tensile strength of the borosilicate glass, because a small leakage in the glass-to-metal joint can produce the loss of vacuum of the receiver and then the loss of energy efficiency (the presence of air within the space between the glass and the steel tubes increases the heat loss, oxidizes the absorber coating and degrades its photo-thermal characteristics over time).
The tightness of the glass-to-metal joints has to be verified with specific experimental tests, taking into account the thermo-mechanical fatigue cycle of operation. The tests have to be based on a statistical approach, to be sure of the reliability of this component over time.

Standards and references

ASTM specification for standard test methods
http://en.wikipedia.org/wiki/Ultimate_strength

Comments

Mechanical test of the ultimate tensile strength has to be performed as a function of temperature

Parameter: Absorbance

Abbr.:

Component: Receiver

Description / Definition:

The solar absorbance of the absorber coating applied on the outer surface of the steel is defined as: $a = 1 - r$. The parameter r, is the reflectance of the absorber coating, that is the ratio of the reflected solar radiation to the normal incident solar radiation.

Unit: %

Importance:

Very important for defining the energy efficiency of the solar receiver

Parameter: Reflectance

Abbr.:

Component: Receiver

Description / Definition:

The solar reflectance is defined as the ratio of the reflected solar radiation to the normal incident solar radiation. The monochromatic spectral reflectivity of the absorber coating $r(\lambda)$, can be measured at defined wavelengths in the range from 300 nm to 2500 nm (ASTM E903), by a spectrophotometer with an integrating sphere.

The solar reflectance is calculated as the average value of the measured spectral reflectivity $r(\lambda)$, weighted over the solar spectrum at the Earth surface $I(\lambda)$ (W m^{-2} nm^{-1}), as specified in ASTM G173, air mass 1.5: $\bar{r} = \frac{\int_{300}^{2500} r(\lambda) I(\lambda) d\lambda}{\int_{300}^{2500} I(\lambda) d\lambda}$

Unit: %

Importance:

The measurement of the solar reflectance of the absorber coating is very important for evaluating the solar absorbance: $\bar{a} = 1 - \bar{r}$

Standards and references

ASTM E903, E892, G173

Parameter: Emissivity

Abbr.: ε

Component: Receiver

Description / Definition:

The thermal emittance *E*(*T*), is defined as the ratio of the thermal radiation emitted from the absorber coating at temperature *T* and the radiation emitted from the black body at the same temperature. The thermal emittance can be measured by an IR emissometer, compliant with ASTM C1371

Unit: %

Importance:

N/D

Standards and references

ASTM E903, E892, G173, C1371

Parameter: Window transmittance

Abbr.:

Component: Receiver

Description / Definition:

Irradiance caused by solar radiation received from a small solid angle centred on the sun's disc, on a plane perpendicular to the vector to the sun’s centre.

Unit: %

Importance:

N/D

Standards and references

N/D

Parameter: Heat Transfer Coefficient

Abbr.: h

Component: Receiver

Description / Definition:

There are several heat transfer mechanisms to take into account for solar receivers tubes of parabolic trough:

- Forced convection for heat exchange between the internal surface of the absorber tube and the heat transfer fluid
- Irradiation between the outer surface of the steel tube and the inner surface of the glass (in case of presence of gas within the cavity with total pressure higher than 10^{-2} mbar there can be also heat exchange by conduction-convection between the two tubes)
- Irradiation between the outer surface of the glass and the environment
- Convection (natural or forced, if the wind speed is higher than 0.16 m/s), between the outer surface of the glass tube and air

Unit: W m^{-2} °C^{-1}

Importance:

The heat transfer between the solar receiver and the environment it's very important for the thermal efficiency of the solar receiver tube

Standards and references

N/D

Comments

The heat exchange coefficient between the steel and the glass tubes can be evaluated in laboratory by tests for evaluating the energy efficiency of the solar receiver tube as a function of the steel temperature

Parameter: Exchange Area

Abbr.: S

Component: Receiver

Description / Definition:

Irradiance caused by solar radiation received from a small solid angle centred on the sun's disc, on a plane perpendicular to the vector to the sun's centre.

Unit: %

Importance:

N/D

Standards and references

N/D

Parameters concerning heat transfer fluids

Revision History

2011/04 Edited by CIEMAT
Jesús Fernández, jesus.fernandez@psa.es

2011/05 Revised by ENEA
Pietro Tarquini, pietro.tarquini@enea.it

Parameter: Density

Abbr.: ρ

Description / Definition:

Mass per unit of volume

Importance:

Is the source for everything?

Standards and references

ISO 3675

Parameter: Thermal Conductivity

Abbr.: *k*

Description / Definition:

Ability of a material to conduct Heat. It is measured in watts per kelvin-meter ($W \cdot K^{-1} \cdot m^{-1}$)

Importance:

Is the source for everything?

Standards and references

ASTM D2717 - 95(2009) Standard Test Method for Thermal Conductivity of Liquids

Parameter: Heat Capacity

Abbr.: C_p

Description / Definition:

Amount of heat required to change a body's temperature by a given amount. In the International System of Units, heat capacity is expressed in units of joules per kelvin.

Standards and references

ASTM D2766 - 95(2009) Standard Test Method for Specific Heat of Liquids and Solids

Parameter: Thermal Diffusivity

Abbr.: ***α***

Description / Definition:

Thermal conductivity divided by the volumetric heat capacity. It has the SI unit of m^2/s.

Standards and references

ASTM Standard D2717-95

Parameter: Thermal Expansion Coefficient

Abbr.: ***k***

Description / Definition:

The fractional of change in size per degree change in temperature at a constant pressure. Several types of coefficients have been developed: volumetric, area, and linear.

Standards and references

ASTM C 531

Parameter: Enthalpy of vaporization

Abbr.: ΔH_{vap}

Description / Definition:

The **enthalpy of vaporization**, also known as the **heat of vaporization** or **heat of evaporation**, is the energy required to transform a given quantity of a liquid substance into a vapour at a given pressure. Units: kJ/kg.

Standards and references

N/A

Parameter: Enthalpy of Fusion

Abbr.: ΔH_{fus}

Description / Definition:

The enthalpy of fusion, also known as the heat of fusion or specific melting heat, is the change in enthalpy resulting from the addition or removal of heat from 1 mole of a substance to change its state from a solid to a liquid (melting) or the reverse processes of freezing. It is also called the latent heat of fusion, and the temperature at which it occurs is called the melting point.

Standards and references

ASTM D3418-99 Standard Test Method for Transition Temperatures of Polymers By Differential Scanning Calorimetry

Standards and references

N/A

Parameter: Fire Bearing Point (Pyrophority)

Abbr.:

Description / Definition:

Temperature at which the fluids ignites spontaneously in contact with ambient air.

Parameter: Flammability

Abbr.:

Description / Definition:

How easily something will burn or ignite, causing fire or combustion

Standards and references

ISO 9772 and 9773.

Parameter: Auto-ignition temperature

Abbr.:

Description / Definition:

The **auto-ignition temperature** or **kindling point** of a substance is the lowest temperature at which it will spontaneously ignite in a normal atmosphere without an external source of ignition, such as a flame or spark.

Standards and references

ASTM Standard D2717-95

Parameter: Vapour Pressure

Abbr.:

Description / Definition:

Pressure of a vapour in thermodynamic equilibrium with its condensed phases in a closed system.

Available Standards:

ASTM Standard D2717-95

Parameter: Boiling point (at normal conditions)

Abbr.: T_b

Description / Definition:

The **boiling point** of an element or a substance is the temperature at which the vapor pressure of the liquid equals the environmental pressure surrounding the liquid

Parameter: Viscosity

Abbr.: μ

Description / Definition:

Resistance of a fluid which is being deformed by either shear stress or tensile stress. Viscosity describes a fluid's internal resistance to flow.

Units: Pa·s = kg/(s·m)

Standards and references

ISO 3104

Parameter: Speed of sound in fluids

Abbr.:

Description / Definition:

Neccessary for ultrasonic flowmeters.

Standards and references

ASTM Standard D2717-95

Parameter: Impurities/degradation components

Abbr.:

Description / Definition:

Contents (in ppm) of components that are results of the degradation on the fluids. Should be divided on heavy and light components/impurities.

Standards and references

ASTM Standard D2717-95

Parameter: Thermal Conductivity

Abbr.: ***k***

Description / Definition:

Ability of a material to conduct Heat. It is measured in watts per kelvin-meter ($W \cdot K^{-1} \cdot m^{-1}$)

Standards and references

ASTM Standard D2717-95

Parameter: Melting point

Abbr.: T_{fm}

Description / Definition:

The melting point of a solid is the temperature at which it changes state from solid to liquid

Parameter: Freezing point

Abbr.: T_{fp}

Description / Definition:

The freezing point of a liquid is the temperature at which it changes state from liquid to solid.

Parameter: Maximum working temperature

Abbr.: T_{wm}

Description / Definition:

Maximum temperature at which the thermo-fluid can operate

Parameters concerning the Power Conversion Unit

Revision History

2011/06 Edited by Weizmann Institute of Science
Michael Epstein, Michael.Epstein@weizmann.ac.il

1. Efficiency of the PCU vs different operating parameters:
   - Steam mass flow
   - Temperature/pressure
   - Condensation conditions
     - 〉 Water and air cooling

2. Standard procedures and measuring methods of the PCU performance (efficiency): gross and net conversion to electricity
3. Standard procedures for commissioning tests of PCU
4. Installation parameters dimensions, weight, space, services
5. Transformation station parameters.
6. Specific parameters for performance and acceptance tests of PCU for different solar technologies:
   - Tower
   - Parabolic trench
   - Dish
   - SCC
7. Operation parameters for CPU operated by solar fuels (e.g. hydrogen, synthesis gas, etc) or hybridization with biomass.