भारतीय मानक

Indian Standard

IS 16543 : 2024

समस्त-ग्लास इवेक्यूएटिड सोलर कलेक्टर ट्यूब — विशिष्टि

(पहला पुनरीक्षण)

All-Glass Evacuated Solar Collector Tubes — Specification

(First Revision)

ICS 23.160

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Renewable Energy Sources Sectional Committee, MED 04

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Renewable Energy Sources Sectional Committee had been approved by the Mechanical Engineering Division Council.

This standard was first published in 2016. The requirements for a storage water tank for use with all-glass evacuated tube collector is covered in IS 16542 and the requirements for all-glass evacuated tubes solar water heater system are covered in IS 16544.

This revision has been taken up to keep pace with the latest technological developments and international practices. This revision incorporates the following major changes:

a) Clauses **5.1.1**, **5.1.2**, **H-3**, **D-2**, **7.4** and Annex B have been modified; and
b) New clause **7.2**, Annex K and Annex L have been added.

In this revision of the standard, considerable assistance has been obtained from the leading manufacturers and users in this country.

While formulating this standard assistance has mainly been derived from the Ministry of New and Renewable Energy working draft STD 01 : 2012 (R) 'Draft standard all-glass evacuated solar collector tubes'.

The relevant SI units and corresponding conversion factors are given below for guidance:

$$
\begin{aligned}
1\ \text{kgf/cm}^2 &= 98.066\ 5\ \text{kPa (kilopascal)} = 10\ \text{m of water column (WC)} \\
&= 0.098\ 066\ 5\ \text{MPa (megapascal)} \\
&= 0.980\ 665\ \text{bar} \\
1\ \text{Pa} &= 1\ \text{N/m}^2
\end{aligned}
$$

The composition of the Committee responsible for the formulation of this standard is given in Annex M.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

ALL-GLASS EVACUATED SOLAR COLLECTOR TUBES — SPECIFICATION

(First Revision)

1 SCOPE

This standard specifies requirements of all-glass evacuated solar collector tubes of non-concentrating type solar collector hot water output up to 80 °C.

2 REFERENCES

The standards given below contain provisions which, through reference in this text, constitute provision of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of these standards:

IS No./Other Standards	*Title*
IS/ISO 9488 : 2022	Solar energy — Vocabulary (*first revision*)
ISO 3585 : 1998	Borosilicate glass 3.3 — Properties
ISO 9845 (Part 1) : 2022	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

3 TERMINOLOGY

For the purpose of this standard, the definitions are given in IS/ISO 9488 and the following shall apply:

3.1 Absorber of All-Glass Evacuated Solar Collector Tube — Inner glass tube with solar selective absorbing coating on its outer surface that absorbs solar radiation and converts it into thermal energy.

3.2 Angle of Incidence — The angle between the direct solar irradiation and the normal to the aperture plane.

3.3 Average Heat Loss Coefficient of an All-Glass Evacuated Solar Collector Tube — Thermal flow lost through the absorber unit surface area under the condition of no solar irradiance for every 1 °C difference between the average temperature of the hot water filling up the all-glass evacuated solar collector tube and the average ambient temperature.

3.4 Bubble (Stone) — Solid impurity contained in the glass body.

3.5 Diffuse Flat Plate Reflector — Flat plate mainly with diffuse reflection, which is installed below at a certain distance from all-glass evacuated solar collector tube and used for increasing the solar radiation collected by the all-glass evacuated solar collector tube.

3.6 Knot — Vitreous body in glass that varies from the main component of glass.

3.7 Pyranometer — A radiometer used to measure the total solar radiation (direct, diffuse, and reflected) incident on a surface per unit time per unit area.

3.8 Reflector or Reflective Surface — A surface intended for the primary function of reflecting radiant energy.

3.9 Solar Irradiance — Irradiance is the rate of solar radiation received by a unit surface area in unit time, in W/m^2.

3.10 Solar Selective Absorbing Coating (Surface) — Coating with high solar absorbing ratio and low emitting ratio.

3.11 Stagnation Temperature — Maximum temperature of the air within the all-glass evacuated solar collector tube under quasi-steady-state at specified solar irradiance when there is only air inside the all-glass evacuated solar collector tube.

3.12 Stagnation Parameter of an All-Glass Evacuated Solar Collector Tube — Ratio of the difference between stagnation temperature and ambient temperature and the solar irradiance.

3.13 Vacuum Jacket in All-Glass Evacuated Solar Collector Tube — Jacket between the cover glass tube and inner glass tube of all-glass evacuated solar collector tube, where air pressure is sufficiently low, thermal conduction and convection of air can be ignored.

3.14 Vacuum Quality — Vacuum performance in the evacuated tube is expressed by the disappearance ratio in axial length of the getter mirror after the interior of an evacuated tube is heated.

3.15 Air Mass — The ratio of the mass of atmosphere in the actual observer-sun path to the mass that would exist if the observer was at sea level, at standard barometric pressure, and the sun was directly overhead.

NOTE — Air mass varies with the declination of the sun and the local barometric pressure which changes with altitude.

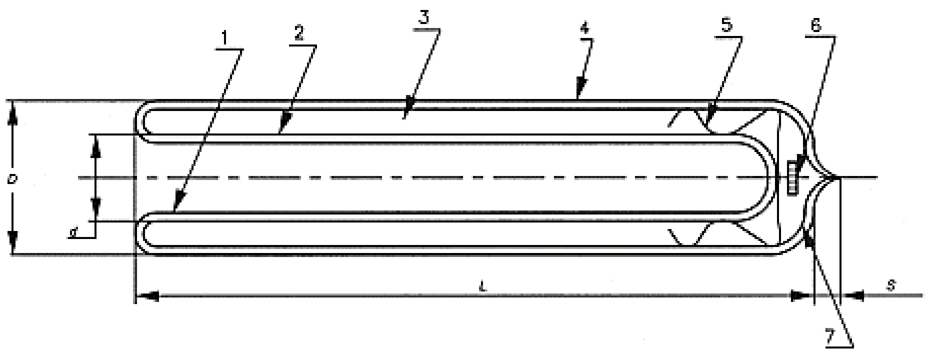
4 DESIGN

4.1 Structure of All-Glass Evacuated Solar Collector Tube

The all-glass evacuated solar collector tube shall comprise the inner glass tube with solar selective absorbing coating on its outer surface and coaxial cover glass tube. The one end of the inner glass tube shall be closed at the base and seated in a steel strut. The other end of the inner glass tube shall be thermally sealed with the other end of the cover glass tube. The space between the inner tube and outer cover tube shall be vacuumed before thermal sealing of the other end of the cover tube.

4.2 Dimensions and Tolerances of All-Glass Evacuated Solar Collector Tubes

The dimensions and tolerances of all-glass evacuated solar collector tubes shall be as shown in Table 1.



Key

1 Inner glass tube;
2 Solar selective absorbing coating;
3 Vacuum jacket;
4 Cover glass tube;
5 Strut member;
6 Getter; and
7 Getter mirror surface

FIG. 1 STRUCTURE OF ALL-GLASS EVACUATED SOLAR COLLECTOR TUBE

Table 1 Dimensions and Tolerances of All-Glass Evacuated Solar Collector Tubes

(*Clause* 4.2)

All dimensions in millimetres.

Sl No.	Outer Diameter of Cover Glass Tube *D*	Outer Diameter of Inner Glass Tube Including Coating *d*	The Thickness of Cover and Inner Glass Tube	Tube Length *L*	Sealed off Part Length *S*
(1)	(2)	(3)	(4)	(4)	(5)
i)	47 ± 1	37 ± 1	1.6 ± 0.1	1 500 ± 5, 1 800 ± 5, 2100 ± 5	
ii)	58 ± 1	47 ± 1	1.6 ± 0.1	1 500 ± 5, 1 800 ± 5, 2 100 ± 5	< 15
iii)	70 ± 1	58 ± 1	2.0 ± 0.1	1 800 ± 5, 2 000 ± 5, 2 100 ± 5	

4.3 Absorber Area for Different Tube Sizes (A_A) (A_A= 3.14 × d × L_1, where $L_1 = L - D/2$)

The minimum absorber areas for different tube sizes of all-glass evacuated solar collector tubes shall be as shown in Table 2.

4.4 Solar Selective Absorbing Coating

The solar selective absorbing coating shall be three target coating having three layer-absorption layers, bonding agent cum absorption layer, and anti-reflection layer.

4.5 Calculation for Number of Tubes for The Heating System

Minimum number of tubes

= Minimum collector area/[0.6 × A_A (minimum absorber area of tube collector)]

NOTE — The minimum collector area per 100 litres per day should be 1.5 m^2.

5 GENERAL REQUIREMENTS

5.1 Material

5.1.1 The material of glass tubes shall be borosilicate glass conforming to ISO 3585. The solar transmittance ratio of the glass tube shall be $\tau \geq 0.89$ (at air mass 1.5, that is AM 1.5).

5.1.2 There shall not be any bubble (stone) bigger than 1 mm on the glass tube and there shall not be more than 1 bubble (stone) within an area of 10 mm × 10 mm and not more than 5 bubbles (stones) on the whole of the tube. There shall be no crack around the bubble.

5.1.3 There shall be no dense knots bigger than 1.5 mm on the glass tube. There shall not be more than 5 knots on the whole tube.

5.1.4 The solar absorbing ratio of solar selective coating shall be a minimum of 92 percent (at AM 1.5). The material for three target coating shall be aluminum nitrate, aluminum nitrate stainless steel, and copper multilayer selective coating and shall conform to the above requirements.

5.2 Appearance and Dimensions

5.2.1 The accumulative length of minor scratches shall not be more than 1/3 tube length and the scratches shall not be visible from a distance of a minimum of 1 200 mm.

5.2.2 The selective coating of the all-glass evacuated solar collector tube shall have no smear, peel off and fade off.

5.2.3 Distance from the obvious colour fading area of the selective absorber coating at the open end of the all-glass evacuated solar collector tube shall be no more than 50 mm.

5.2.4 The strut member supporting the free end of the inner glass tube shall be properly placed and shall not be loose.

Table 2 Absorber Area for Different Tube Sizes

(*Clause* 4.3)

All dimensions in millimetres.

Sl No.	Outer Diameter of the All-Glass Evacuated Solar Collector Tube	Length of the All-Glass Evacuated Solar Collector Tube	Minimum Absorber Area (A_A) of All-Glass Evacuated Solar Collector Tube m^2
(1)	(2)	(3)	(4)
i)	47	1 500	0.172
		1 800	0.206
		2 000	0.230
		2 100	0.241
ii)	58	1 500	0.217
		1 800	0.261
		2 000	0.291
		2 100	0.306
iii)	70	1 500	0.267
		1 800	0.321
		2 000	0.358
		2 100	0.376

5.2.5 The inner and cover tube at the open end of the all-glass evacuated solar collector tube shall have smooth ends without any glass peel-off and shall not have any deformation.

5.2.6 The length of an all-glass evacuated solar collector tube is the distance from the open end to the point at which the diameter of the outer glass cover measured 15 mm.

5.2.7 Bending of the all-glass evacuated solar collector tube shall not be more than 0.2 percent of the length of the tube.

5.2.8 The cross-section of the open end of all-glass evacuated solar collector tube at a distance of (20 ± 10) mm from the open end is of a round shape. The ratio of the radius maximum size to the minimum size of the cover glass is no more than 1.02.

5.2.9 The sealed end of the tube shall not have any sharp end and shall be smooth.

6 TEST SET UP

6.1 Solar radiation shall be measured using a Class I Pyranometer on the plane of the solar collector. For this, a mounting stand shall be used.

6.2 For measuring ambient air temperature, the measuring sensor (a calibrated RTD) shall be located shaded by a Stevenson screen in the vicinity of the test set-up (not more than 10 m from it). It shall be ensured that there is no obstruction by any structure or building to alter (block or enhance) the free flow of the natural wind to the sensor. The outside surface of the Stevenson screen shall be of light colour, preferably white, and its bottom shall be kept at least 1 m above the ground level.

6.3 The surrounding airspeed shall be measured on the collector surface at about its middle every 30 min with an accuracy of ± 0.1 m/s and the average value of the test duration shall be reported along with the test results.

7 TEST REQUIREMENTS

The following tests shall be performed on a sample of an all-glass evacuated solar collector tube.

7.1 Dimensions

It shall conform to the requirements given in **4.2**.

7.2 Material

7.2.1 It shall conform to the requirements given in **5.1** and solar transmittance as per Annex K.

7.2.2 Uniformity of the tube glass shall be visually inspected as per Annex L.

7.3 Appearance and Dimensions

It shall conform to the requirements given in **5.2**.

7.4 Stagnation Performance Parameter Test

The stagnation performance (*Y*) shall not be less than 190 m^2 °C/kW when tested as per Annex A.

7.5 Stagnation Solar Irradiation Test

The stagnation solar irradiation, when tested as per Annex B shall be as under:

a) Not more than 3.7 MJ/m^2 for 47 mm outside diameter cover glass tube;
b) Not more than 4.7 MJ/m^2 for 58 mm outside diameter cover glass tube; and
c) Not more than 5.7 MJ/m^2 for 70 mm outside diameter cover glass tube.

7.6 Average Heat Loss Coefficient Test

The average heat loss coefficient (U_{LT}) shall be less than 0.85 W/m^2 °C when tested as per Annex C.

7.7 Vacuum Performance Test

It shall meet the requirement given in Annex D.

7.8 Resistance to Thermal Shock Test

There shall be no cracks developed when tested as per Annex E.

7.9 Resistance to Impact Test

There shall be no damage/crack when tested as per Annex F.

7.10 Resistance to Internal Pressure Test

There shall be no damage when tested as per Annex G.

7.11 Absorptivity and Emissivity Test of the Selective Coating

The selective coating of the tube shall have a minimum of 0.92 absorptivity and emissivity less than 7 percent when tested as per Annex H.

8 TEST REPORT

A test report shall be generated in the format given in Annex J.

9 MARKING

9.1 Designation

The all-glass evacuated solar collector tubes may also be marked with the manufacturer's trademark or logo, batch number, or date of manufacture. Designation of all-glass evacuated solar collector tube shall comprise of following five parts:

a) Part 1: All-glass evacuated solar collector tube;
b) Part 2: Chemical symbol of solar selective coating;
c) Part 3: Outer diameter of cover glass and inner glass tube;
d) Part 4: Length of tube; and
e) Part 5: Type of coating (three targets).

Example:

All-glass evacuated solar collector tubes having AlN/AlN-SS/Cu multilayer selective coating with 58 mm outer diameter of a cover glass tube and 47 mm outer diameter of inner glass tube, 1 800 mm length and three target coating shall be designated as:

ET - AlN/AlN-SS/Cu - 58/47 – 1 800 - 3T.

9.2 BIS Certification Marking

The product(s) conforming to the requirements of this standard may be certified as per the conformity assessment schemes under the provisions of the *Bureau of Indian Standards Act*, 2016 and the Rules and Regulations framed there under, and the products may be marked with the Standard Mark.

10 PACKING

All-glass evacuated solar collector tubes shall be suitably packed in boxes to avoid any damage during handling, storage, and transportation.

ANNEX A

(*Clauses* 7.4, B-1, B-2 *and* C-2.1)

STAGNATION PERFORMANCE PARAMETER TEST

A-1 TEST CONDITION

These measurements shall be conducted outdoors. The plane on which the pyranometer is placed shall be parallel with the plane of a collector. Solar irradiance $G \geq 800$ W/m^2 ± 30 W/m^2, ambient temperature 20 ºC ≤ t_a ≤ 39 ºC, and wind velocity ≤ 4 m/s.

A-2 TEST BENCH SET UP

Place all 3 glass evacuated solar collector tubes in parallel in the south-north direction. All-glass evacuated solar collector tubes to be tested shall be in the middle and the other two tubes are accompanying test tubes. The centre to centre spacing between the tubes shall be twice the inner tube diameter. The centre to the diffuse flat plate reflector spacing is 70 mm. The flat plate reflector has a diffuse reflectance not less than 0.60. Air is used as the thermal conducting medium inside the all-glass evacuated solar collector tube, the temperature shall be measured at the centre of the tube and the sensor shall not contact the wall of the glass tube. A 50 mm thick rigid polyurethane foam is used as a thermal insulation cap at the open end of the all-glass evacuated solar collector tube. The cap shall not cover the selective surface. The angle of inclination between the horizontal plane and all-glass evacuated solar collector tube is ± 5° of latitude of the location but not less than 30°. The measuring device is to be set up as shown in Fig. 2.

A-3 TEST PROCEDURE

When the solar irradiance is $G \geq 800$ W/m^2 ± 30 W/m^2 record the solar irradiance, temperature inside the collector tube, and ambient temperature every 5 min, take 4 readings. Take the average value of the 4 readings of solar irradiance as solar irradiance G. Similarly, take the average value of 4 readings of the temperature inside the collector tube and ambient temperature as temperatures t_s and t_a, respectively.

A-4 TEST INSTRUMENTS

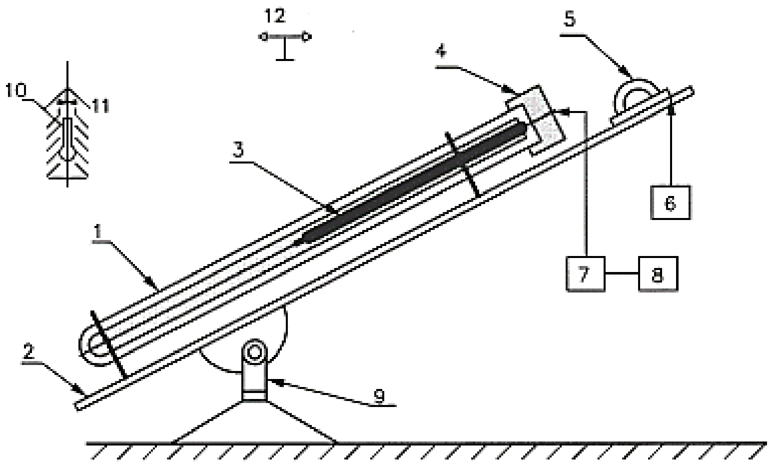
a) Pyranometer, Class 1;
b) Platinum resistance thermometer or RTD sensor;
c) Mercury thermometer; and
d) Anemometer.

A-5 Calculate the stagnation performance parameter Y of all-glass evacuated solar collector tube according to eq (1):

$$Y = \frac{t_s - t_a}{G} \qquad \ldots(1)$$

where

Y = Stagnation performance parameter, m^2°C/kW;
t_s = Stagnation temperature, ºC;
t_a = Average ambient temperature, ºC; and
G = Solar irradiance, kW/m^2.



Key

1 All-glass evacuated tube collector

2 Diffuse flat plate reflector

3 Platinum resistance thermometer

4 Thermal insulation cap

5 Pyranometer

6 Radiation recording device

7 Temperature testing device

8 Data logger

9 Mounting frame

10 Mercury thermometer

11 Thermometer housing

12 Anemometer

FIG. 2 SCHEMATIC DIAGRAM OF THERMAL PERFORMANCE TESTING DEVICE OF ALL-GLASS EVACUATED SOLAR COLLECTOR TUBE

ANNEX B

(*Clauses Foreword and* 7.5)

STAGNATION SOLAR IRRADIATION TEST

B-1 TEST CONDITIONS

Same as in **A-1**.

B-2 TEST BENCH SET UP

Same as in **A-2**. All-glass evacuated solar collector tube uses water as the thermal conducting medium.

B-3 TEST PROCEDURE

Cover the all-glass evacuated solar collector tube with an opaque cover. Fill the water. Initially, the water temperature should be lower than ambient. As soon as the water temperature is equal to ambient temperature, record the initial solar irradiation. Expose all-glass evacuated solar collector tube to the sun by removing the opaque cover. When water temperature inside the tube rises by 35 °C record the final solar irradiation. The difference between final solar irradiation and initial solar irradiation is stagnation solar irradiation.

ANNEX C

(*Clause* 7.6)

AVERAGE HEAT LOSS COEFFICIENT TEST

C-1 TEST CONDITIONS

This test shall be conducted indoors. The average ambient temperature during the testing period is 20 °C $\leq t_a \leq$ 30 °C and there is no wind directly blowing onto the all-glass evacuated solar collector tube.

C-2 TEST BENCH SET UP

C-2.1 All-glass evacuated solar collector tube is placed vertically to the horizontal plane. The open end is covered by the same thermal insulation cap as in **A-2**.

C-2.2 There shall be three temperature measuring points from top to bottom in the all-glass evacuated solar collector tube. The measurement points are given as under:

Sl No. (1)	*Tube Length* (*L*) mm (2)	*Distance from Open End to the Measurement Points* mm (3)
i)	1 500	250, 750, 1 250
ii)	1 800	300, 900, 1 500
iii)	2 000	335, 1 000, 1 665
iv)	2 100	350, 1 050, 1 750

C-3 TEST PROCEDURE

Fill up all-glass evacuated solar collector tube with hot water of minimum temperature 90 °C and drain it out after 2 min. Immediately after this preheating, fill up the all-glass evacuated solar collector tube with hot water of minimum temperature 90 °C. The water level must be up to a height of 40 mm from the top of the tube (open end) for tube length up to 1 500 mm and, up to a height of 50 mm from the top of the tube (open end) for a tube length of 1 800 mm to 2 100 mm. Record the first average temperature (t_1) of the 3 measuring points as defined in the table of **C-2.2**, when the water temperature naturally drops to an average of (80 ± 0.2) °C. Record the second and third average temperature (t_2 and t_3) of three measuring points at an interval of 30 min each. Simultaneously, record the corresponding three ambient temperatures (t_{a1}, t_{a2} and t_{a3}) at the same time.

C-4 TEST INSTRUMENT

a) Platinum resistance thermometer; and
b) Mercury thermometer.

C-5 Calculate the average heat loss coefficient U_{LT} of the all-glass evacuated solar collector tube according to eq (2), eq (3) and eq (4).

$$U_{LT} = \frac{C_{pw} \cdot M(t_1 - t_3)}{A_A(t_m - t_a)\Delta_\tau} \quad \text{...(2)}$$

$$t_m = \frac{t_1 + t_2 + t_3}{3} \quad \text{...(3)}$$

$$t_a = \frac{t_{a1} + t_{a2} + t_{a3}}{3} \quad \text{...(4)}$$

where

U_{LT} = average heat loss co-efficient, W/(m^2 °C);
C_{pw} = specific heat of water, J/kg °C;
M = mass of water inside the all-glass evacuated solar collector tube, kg;
t_1, t_2, t_3 = three average water temperatures inside all-glass evacuated solar collector tube at three measuring points each, °C;
A_A = absorber surface area, m^2 (*see* **4.4**);
t_m = the average water temperature inside the all-glass evacuated solar collector tube during the test, °C;
t_a = average ambient temperature, °C;
Δ_τ = total testing time from water temperature t_1 to t_3, s; and
t_{a1}, t_{a2}, t_{a3} = the corresponding ambient temperature recorded at the same time, °C; and

ANNEX D

(*Clause* 7.7)

VACUUM PERFORMANCE TEST

D-1 AIR PRESSURE TEST INSIDE THE VACUUM JACKET

Use a spark leak detector to probe the vacuum jacket of the open end of the all-glass evacuated solar collector tube. The intensity of spark and colour shall be used to check the vacuum standard.

D-2 VACUUM QUALITY TEST

Electric heating rod (single-end outlet, diameter of 20 mm and rated power of 1 500 W) not less than

90 percent, the length of the collector tube is placed inside all-glass evacuated solar collector tube. The electric heating rod is fixed with an aluminum fin type arrangement before being put into the collector tube. Both ends of the aluminum fins are covered with asbestos cloth to prevent direct contact of the aluminum wing with the collector tube wall. The opening of the collector tube is covered with fibre glass. A thermocouple is placed in the middle of the collector tube to measure the inner glass tube temperature. The temperature of the inner glass tube is maintained at (340 ± 10) °C for 48 h. The change in the mirror surface of the getter is measured. The measurement will be made from the point of a diameter of 15 mm of the sealed-off end of the collector tube to the getter mirror surface edge. There shall be measurement at six equal portions. The average value of the 6 points represents the getter mirror surface axial length. If the rate at which the getter mirror has disappeared is not more than 50 percent, it qualifies the criteria.

For a double-glass evacuated tube, the disappearance percentage in axial length of the getter mirror shall be calculated according to the following formula:

$$R = \frac{L_1 - L_2}{L_1} \times 100$$

where

R = disappearance percentage in axial length of the getter mirror;

L_1 = axial length of the getter mirror before heating, mm; and

L_2 = axial length of the getter mirror after heating, mm.

D-3 ACCEPTANCE CRITERIA

R shall be less than 50 percent.

ANNEX E

(*Clause* 7.8)

RESISTANCE TO THERMAL SHOCK TEST

E-1 TEST CONDITIONS

This test shall be performed indoors.

E-2 Insert the open side of the all-glass evacuated solar collector tube into water having temperature ≤ 1 °C for a depth not less than 100 mm and keep it for 1 min. Take it out and immediately immerse it into a hot water bath of temperature not less than 90 °C for a depth not less than 100 mm and keep it for 1 min. Take it out and immediately immerse in the water having temperature ≤ 1 °C. Repeat this test three times and the all-glass evacuated solar collector tube shall not have any damage.

ANNEX F

(*Clause* 7.9)

RESISTANCE TO IMPACT TEST

F-1 TEST CONDITIONS

This test shall be performed indoors.

F-2 Fix the all-glass evacuated solar collector tube on the test frame supported by 2 V-shaped grooves with 5 mm thick polyurethane liner with 500 mm space in between. A steel ball, having a mass of (120 ± 10) g, shall be dropped from a height of 450 mm oriented to the middle of the collector tube. The steel ball drops freely with vertical impact on the collector tube and the collector tube shall have no damage.

ANNEX G

(*Clause* 7.10)

RESISTANCE TO INTERNAL PRESSURE TEST

G-1 TEST CONDITION

This test shall be performed indoors.

G-2 Fill the all-glass evacuated solar collector tube with water. Increase the water pressure evenly to 0.6 MPa and keep it for 1 min. The all-glass evacuated solar collector tube shall not have any damage.

ANNEX H

(*Clause* 7.11)

ABSORPTIVITY AND EMISSIVITY TEST OF THE SELECTIVE COATING

H-1 TEST CONDITIONS

This test shall be performed indoors.

H-2 TEST PROCEDURE FOR ABSORPTIVITY

Use a spectrophotometer with an integral ball to measure the transmission ratio of the solar selective absorbing coating respectively at 150 mm from the open end of the all-glass evacuated collector tube and at the middle of the collector tube length within a wavelength of 0.3 µm to 2.5 µm. Then calculate the solar absorbing ratio at AM 1.5 and use the average value of the two to express the solar absorbing ratio of the solar selective absorbing coating inside the all-glass evacuated solar collector tube.

H-3 TEST PROCEDURE FOR EMISSIVITY

The hemispherical emittance of the selective absorbing coating on the outside of the inner glass tube of a double-glass evacuated tube is determined by steady state calorimetry at a temperature of (80 ± 5) °C.

NOTE — The gas pressure in the vacuum jacket is typically around 5×10^{-2} Pa, so the conduction of gas molecules can be ignored.

The hemispherical emittance of the selective surface ε_h is as given in

$$\varepsilon_h = \frac{IU}{\sigma A_1 (T_1^4 - T_2^4)} = \frac{q_s}{q_b}$$

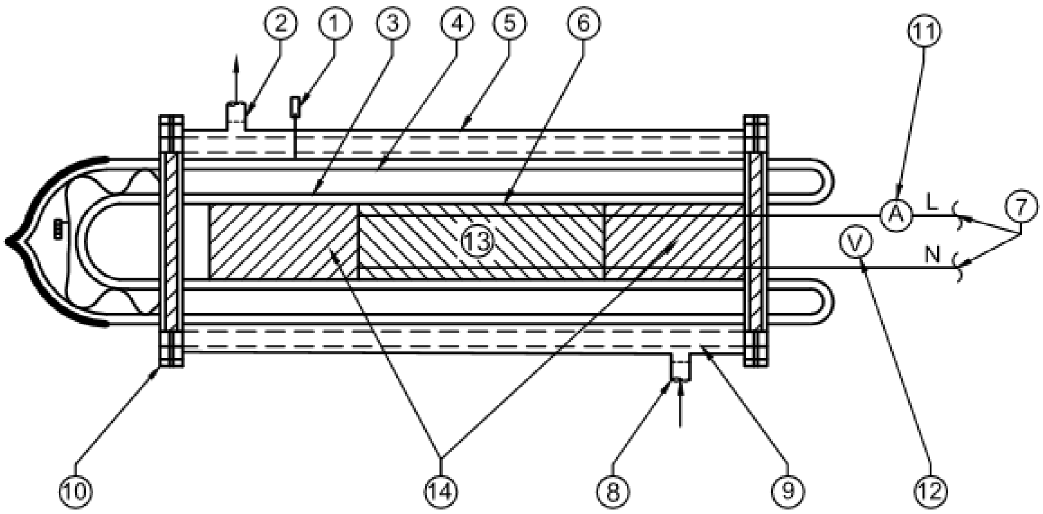
where

I = current of a heater, A;
U = voltage of heater, V;
σ = stefan-Boltzmann constant, 5.67×10^{-8} $Wm^{-2}K^{-4}$;
A_1 = reference area of the outside of inner glass tube, m2;
T_1 = temperature of a heater at steady state, K;
T_2 = temperature of cooling water, K;
q_s = emissive power density of selective absorbing surface, Wm^{-2}; and
q_b = emissive power density of black body, Wm^{-2}.

A double-glass evacuated tube is placed into a water-cooled jacket and heating elements are inserted into the tube. The heating elements consist of the central main heater and the compensating heaters at the ends of the main heater.

The heater elements are contained within three segments of a ceramic tube which fit within the inner glass absorber tube. Temperature sensors are attached to each ceramic element allowing the temperature of each to be measured and controlled independently. The temperature sensor in the inner tubes shall be recorded to a standard uncertainty of 0.2 K. The power dissipated in the central heater required to maintain the absorber tube at a chosen constant temperature is used to evaluate the average heat loss of the heater. The outer segments are maintained at the same temperature as the central segment by means of independent power inputs, to prevent longitudinal heat flow. Consequently, only radial dissipation of the power needs to be considered. The glass envelope is enclosed in a water cooled jacket and its temperature is thus maintained at 20 °C.

Operate the apparatus until the heaters have stabilized at a temperature of (80 ± 5) °C. Determine the voltage, U, and current, I, supplied to the main heater. Determine the reference area, A_1, of the outer surface of the inner glass tube in direct contact with the main heater. Calculate the hemispherical emittance in accordance with the formula mentioned above. Fig. 3 shows the typical sketch of test apparatus for hemispherical emittance.



Key

1	Temperature (t_1) sensor of cooling water
2	Outlet of cooling water
3	Inner glass tube
4	Envelope glass tube
5	Water cooled jacket
6	Temperature (t_2) sensor of central heater
7	Wires of central heater
8	Inlet of cooling
9	Cooling water
10	Sealing flanges of water cooled jacket
11	Amperemeter
12	Voltmeter
13	Central heater
14	Auxiliary heater

FIG. 3 TEST APPARATUS FOR HEMISPHERICAL EMITTANCE

ANNEX J

(*Clause* 8)

PERFORMA OF TEST REPORT

J-1 OFFICIAL STATIONARY OF THE TEST LABORATORY/INSTITUTION ADDRESS AND CONTACT DETAILS

Sl No.	TEST REPORT		
i)	**General**		
	a)	Name and address of manufacturer/supplier	
	b)	Contact details of manufacturer/supplier	
	c)	Details of the sample submitted/model	
	d)	Latitude and longitude of test laboratory: 1) Latitude 2) Longitude	
	e)	Duration of the test: 1) Date of submission 2) Date of completion	
ii)	**Specifications of the Test Sample** (All dimensions in millimetres, unless specified otherwise)		
iii)	**Evacuated Tube (ET)**		
	a)	Make/model	
	b)	Complete address of the manufacturer including e-mail/web site etc.	
	c)	Type	All-glass evacuated solar collector tube
	d)	Tube length, *L*	
	e)	Outer diameter of inner tube (as per manufacturer's report), *d*	
	f)	Outer diameter of outer tube, *D*	
	g)	Details of selective coating(as per manufacturer's report)	
	h)	Aperture (exposed) area of a single tube	
iv)	**Test Results**		
	a)	Stagnation performance parameter test	
	b)	Resistance to thermal shock test	
	c)	Stagnation solar irradiance test	
	d)	Average heat loss coefficient test	
	e)	Resistance to internal pressure test	
	f)	Resistance to impact test	
	g)	Vacuum performance test: 1) Air pressure test 2) Vacuum quality test	
	h)	Selective coating 1) Absorptivity test 2) Emissivity test	
	j)	Any other details	
	k)	Remarks	

Date:
Place:

(Testing Officer) **(Head of the Test Laboratory)**

ANNEX K

(*Clauses Foreword and 7.2.1*)

TEST TO CHECK TRANSMITTANCE OF GLASS TUBE

K-1 GENERAL

This test will determine the solar transmittance (AM 1.5) of the envelope glass tube.

K-2 TEST CONDITIONS AND APPARATUS

This test shall use a spectrophotometer with a wavelength accuracy of ± 1 nm, resolution of 0.1 nm, range of 0.3 µm to 2.5 µm, and an integrating-sphere unit. The measuring spot of the spectrophotometer and the opening of the integrating sphere shall be sized to ensure that the curvature of the tube has no influence on the result.

K-3 TEST PROCEDURE

The solar transmittance of a sample piece of the envelope tube is tested twice. In the first test, place the sample into the measuring spot with the light incident on the concave surface and measure the transmittance of the sample with the spectrophotometer for solar spectral irradiance according to ISO 9845-1. In the second test, place the sample into the measuring spot with the light incident on the convex surface and measure the transmittance of the sample with the spectrophotometer for solar spectral irradiance according to ISO 9845-1.

K-4 RESULTS

The transmittance for solar spectral irradiance according to ISO 9845-1 shall be reported for both measurements and the mean value of the two measurements.

K-5 ACCEPTANCE CRITERIA

Transmittance > 0.89.

ANNEX L

(*Clauses Foreword and 7.2.2*)

TEST TO CHECK UNIFORMITY OF GLASS TUBE

L-1 TEST CONDITIONS

The test room/table for taking observations shall have a minimum illuminance of 1 500 lx.

L-2 APPARATUS

The dimension measurement instrument shall have an accuracy of ± 0.1 mm.

L-3 TEST PROCEDURE

a) Draw two lines with a permanent marker or other non-invasive marking method with thickness no more than 0.5 mm on the surface of the tube along the axial direction, such that the surface is split into two equal parts;

b) With one part upward, count and separately record for this part the numbers of the following:

   1) Stones with size not over 1 mm;
   2) Stones with size over 1 mm;
   3) Knots with size not over 1.0 mm;
   4) Knots with size between 1.5 mm and 2.0 mm;
   5) Knots with size over 2.0 mm; and
   6) Cracks around the stones and knots.

c) Turn the other part of the tube upward and repeat step (b);

d) Sum the values from step (b) and step (c) for each category of stone, knot, or crack;

e) Draw another pair of lines parallel with the first pair of lines, ensuring that the distance between lines is 1/4 of the perimeter. Erase the first pair of lines and count and record the stones, knots, and cracks again as in step (b) to step (d); and

f) For each category of stone, knot, or crack, take the larger of the values recorded in steps (d) and step (e) as the result.

L-4 RESULTS

a) The number of stones with size not over 1 mm, per unit area of the tube;
b) The number of stones with size over 1 mm on the whole tube;
c) The total number of stones on the whole tube;
d) The number of knots with size not over 1.0 mm, per unit area of the tube;
e) The number of knots with size between

1.5 mm and 2.0 mm on the whole tube;

f) The number of knots with size over 2.0 mm on the whole tube; and

g) The number of cracks on the whole tube.

L-5 TEST RESULT FORMAT

Sl No.	Parameters	Nos.
	a) Upper section of tube	
i)	Stones with size not over 1 mm	
ii)	Stones with size over 1 mm	
iii)	Knots with size not over 1.0 mm	
iv)	Knots with size between 1.5 mm and 2.0 mm	
v)	Knots with size over 2.0 mm	
vi)	Cracks around the stones and knots	
	b) Lower section of tube	
vii)	Stones with size not over 1 mm	
viii)	Stones with size over 1 mm	
ix)	Knots with size not over 1.0 mm	
x)	Knots with size between 1.5 mm and 2.0 mm	
xi)	Knots with size over 2.0 mm	
xii)	Cracks around the stones and knots	
	c) Sum of (a) and (b) above	
xiii)	Stones with size not over 1 mm	
xiv)	Stones with size over 1 mm	
xv)	Knots with size not over 1.0 mm	
xvi)	Knots with size between 1.5 mm and 2.0 mm	
xvii)	Knots with size over 2.0 mm	
xviii)	Cracks around the stones and knots	
	d) Upper redrawn section of tube	
xix)	Stones with size not over 1 mm	
xx)	Stones with size over 1 mm	
xxi)	Knots with size not over 1.0 mm	
xxii)	Knots with size between 1.5 mm and 2.0 mm	
xxiii)	Knots with size over 2.0 mm	
xxiv)	Cracks around the stones and knots	
	e) Lower redrawn section of tube	
xxv)	Stones with size not over 1 mm	
xxvi)	Stones with size over 1 mm	
xxvii)	Knots with size not over 1.0 mm	
xxviii)	Knots with size between 1.5 mm and 2.0 mm	
xxix)	Knots with size over 2.0 mm	
xxx)	Cracks around the stones and knots	
	f) Sum of (d) and (e) above	
xxxi)	Stones with size not over 1 mm	
xxxii)	Stones with size over 1 mm	
xxxiii)	Knots with size not over 1.0 mm	
xxxiv)	Knots with size between 1.5 mm and 2.0 mm	
xxxv)	Knots with size over 2.0 mm	
xxxvi)	Cracks around the stones and knots	
	g) Lower redrawn section of tube	
xxxvii)	Stones with size not over 1 mm	
xxxviii)	Stones with size over 1 mm	
xxxix)	Knots with size not over 1.0 mm	
xl)	Knots with size between 1.5 mm and 2.0 mm	
xli)	Knots with size over 2.0 mm	
xlii)	Cracks around the stones and knots	

ANNEX M

(*Foreword*)

COMMITTEE COMPOSITION

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Organization	*Representative(s)*
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