SCHOTT is a leading international technology group in the areas of specialty glass and glass-ceramics. With more than 130 years of outstanding development, materials and technology expertise we offer a broad portfolio of high-quality products and intelligent solutions that contribute to our customers’ success.

With a production capacity of more than 140,000 tons and production sites in Europe, South America and Asia, SCHOTT Tubing is one of the world’s leading manufacturers of glass tubes, rods and profiles. More than 60 different glass types are produced in a large variety of dimensional and cosmetic specifications based on a standardized production process and a global quality assurance system. SCHOTT Tubing provides customized products and services for international growth markets such as pharmaceuticals and electronics as well as industrial and environmental engineering.
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Safety Measures

You are dealing with glass components. It is their natural behavior upon breakage to create pointed and sharp pieces that may cause injuries. Generally, handle glass with care!

Do not stand close to the photobioreactor longer than necessary. The glass components are designed for much higher loads than those occurring during general operation, but it is the natural behavior of glass to sometimes also break at very low stress (although at extremely low statistical probability).

Whenever being close to the photobioreactor, wear goggles, safety gloves, safety shoes and solid clothing which covers the complete body. Ideally, to avoid accidental approach to the photobioreactor, close off the complete area by fences.

When carrying glass components, e.g. after unpacking or during restructuring of the PBR, the walk-ways should be clear and should provide sufficient space not to hit other objects.

Tubes that obviously have mechanical defects (scratches, cracks, etc.) should not be installed or put into operation. These tubes have an increased risk of breakage.

When installing or renewing tubes at an elevated position, take care that no people are located underneath – ideally, close off the area.

SCHOTT recommends wearing goggles and work gloves during transport and handling of glass components and safety shoes when handling heavy glass components.
SCHOTT recommends wearing safety goggles and work gloves when cleaning up broken pieces of glass.

SCHOTT recommends a leak test of the entire photobioreactor before commissioning. The inside pressure should be increased to above the maximum expected operating pressure, but should never exceed the specified maximum system pressure.

SCHOTT recommends the installation of pressure sensors that open up safety valves and shut down pumps at given maximum pressures. The sensors should be installed at positions where the highest inside pressures are expected. Note that the inside pressure has three individual contributions: hydrostatic and hydrodynamic pressure components and pressure burst from the pumps. In a worst case scenario, the pump may operate against a clogged tube and build up very high pressures inside the tubular system.

Take care that the tubes lie firmly in their final positions and that the U-bends are mounted correctly to prevent them from being pushed off when the PBR is pressurized.

PBR system/microalgae plant: ecoduna, Austria
Installation Instructions

This document provides recommendations and information for the handling and installation of glass tubes for photobioreactors. It refers to all dimensions and gives specific information for tubes with standard diameters of 54 mm, 65 mm and 100 mm.

Installation – General Comments

The tubes are made of glass. Handle them with care and avoid all contact of the glass components with any other solid objects. When handling the glass tubes and laying them into the supports for their final position always deploy at least two people.

Wear at all times goggles, safety gloves, safety shoes and solid clothing which covers the complete body.

Never let two tube ends get into direct contact with each other. They may break, or the contact may cause small microcracks that can lead to breakage during operation.

Make sure that both, tube ends and couplings are clean before installation. In particular, any sand or similar abrasive material that might scratch the glass surface must be completely removed.

SCHOTT couplings provide a spacer on the inside to prevent the glass tubes from touching each other.

Handle glass with care: Lay in tubes with two persons.

Use the SCHOTT tool kit for a correct and safe handling. Please note for standard couplings a 40Nm torque should be applied and 25Nm torque for the slim couplings.

The Video Tutorial shows a detailed instruction: www.schott.com/pbr-tutorial
**Support Distance**

It is required to support the tubes at two symmetric positions that typically lie at one quarter of the total tube length from either tube end. The following support positions are recommended by SCHOTT – given as distances from each end:

<table>
<thead>
<tr>
<th>Tube Size</th>
<th>54 mm tube</th>
<th>65 mm tube</th>
<th>100 mm tube</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L = 5,500 mm</td>
<td>L = 5,500 mm</td>
<td>L = 3,850 mm</td>
</tr>
<tr>
<td>First support</td>
<td>1375 mm</td>
<td>1375 mm</td>
<td>950 mm</td>
</tr>
<tr>
<td>[mm]</td>
<td>54.1 inch</td>
<td>54.1 inch</td>
<td>37.4 inch</td>
</tr>
<tr>
<td>Unsupported middle</td>
<td>2750 mm</td>
<td>2750 mm</td>
<td>1950 mm</td>
</tr>
<tr>
<td>[mm]</td>
<td>108.3 inch</td>
<td>108.3 inch</td>
<td>76.8 inch</td>
</tr>
<tr>
<td>Second support</td>
<td>1375 mm</td>
<td>1375 mm</td>
<td>950 mm</td>
</tr>
<tr>
<td>[mm]</td>
<td>54.1 inch</td>
<td>54.1 inch</td>
<td>37.4 inch</td>
</tr>
</tbody>
</table>

Table 1: Support distances for glass tubes. In these configurations the ends of water-filled tubes will sag by less than 5 mm and the ends will form an angle of less than 1° with the horizontal.

Ensure that tube supports are capable of holding the maximum mass of a water filled tube as specified below under „Data Sheet Glass Tubes“ (see page 9).

**Support Shape and Material**

The tube support should hold the tube in place while not exerting a pressure higher than 1 MPa onto the glass surface. SCHOTT recommends supports with round, bowl-like shapes that hold the tubes in place and that distribute the pressure over large areas on the tube perimeter. The material in immediate contact with the glass tube should be a soft material, e.g. a polymer or rubber sleeve on a metal support. Avoid direct metal-glass contacts and mechanical stress peaks.

**Max. pressure of support on tube**

1 MPa | 145 psi

**Support shape**

round (bowl like)

**Support area in contact with the tube**

> 10 cm² | 1.5 in²

**Surface material in contact with tube**

a soft material like rubber or polymer

**Couplings**

When connecting tubes or glass components a direct glass-to-glass contact must be avoided. Couplings should keep the tube ends apart from each other and should provide a smooth tube-to-tube transition. Note that under thermal expansion the tube ends approach each other. SCHOTT couplings are designed for compensating this expansion.

Please note for standard couplings a **40 Nm torque** should be applied and **25 Nm torque** for the slim couplings.

<table>
<thead>
<tr>
<th>Thermal expansion [mm] [inch]</th>
<th>54 mm tube L = 5,500 mm</th>
<th>65 mm tube L = 5,500 mm</th>
<th>100 mm tube L = 3,850 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆T = 20 °C = 36 °F</td>
<td>0.36 0.014</td>
<td>0.36 0.014</td>
<td>0.25 0.010</td>
</tr>
<tr>
<td>∆T = 40 °C = 72 °F</td>
<td>0.73 0.029</td>
<td>0.73 0.029</td>
<td>0.51 0.020</td>
</tr>
</tbody>
</table>

Table 2: Thermally induced expansion of glass tubes at two exemplary temperature changes
**Inside Pressure**
Water does not flow frictionless. Be aware that when connecting multiple tubes and U-bends pressure builds up and – in long systems – this pressure can exceed the maximum specified pressure. In cases of too high flow resistances the flow speed may be reduced or shorter loops must be designed.

**U-Bends**
Internal pressure in the PBR can generate forces that can push off a U-bend. To prevent this from happening be sure to securely mount the U-bends to the adjacent tubes and prevent them from moving outward by attaching them to the rack with a wire or by placing a post against the U-bend to block movement.

Inside pressures and forces that tend to push off each U-bend arm:

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Force</th>
<th>Force</th>
<th>Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 bar</td>
<td>200</td>
<td>288</td>
<td>694</td>
</tr>
<tr>
<td>2 bar</td>
<td>399</td>
<td>577</td>
<td>1388</td>
</tr>
<tr>
<td>3 bar</td>
<td>599</td>
<td>865</td>
<td>2082</td>
</tr>
</tbody>
</table>

Table 3: Force on each arm of a U-bend as a function of inside pressure and outside tube diameter. Conversion: 1 bar = 14.5 psi

**Data Sheet Glass Tubes**
The following gives an overview of nominal values of standard tube parameters that may be useful for installation.

Coefficient of thermal expansion \([K^{-1}]\): \(3.3 \times 10^{-6}\)

<table>
<thead>
<tr>
<th>OD WT</th>
<th>54 mm tube</th>
<th>65 mm tube</th>
<th>100 mm tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD</td>
<td>54 mm</td>
<td>65 mm</td>
<td>100 mm</td>
</tr>
<tr>
<td>WT</td>
<td>1.8 mm</td>
<td>2.2 mm</td>
<td>3.0 mm</td>
</tr>
<tr>
<td>1 bar</td>
<td>200</td>
<td>288</td>
<td>694</td>
</tr>
<tr>
<td>2 bar</td>
<td>399</td>
<td>577</td>
<td>1388</td>
</tr>
<tr>
<td>3 bar</td>
<td>599</td>
<td>865</td>
<td>2082</td>
</tr>
</tbody>
</table>

Table 4: Overview of standard tube geometries and quantities (all nominal values).
Conversion: 1 pound (lb) = 0.4536 kg, 1 inch = 25.4 mm, 1 gallon (gal) = 3.7854 l
Operating Instructions

**Inside Pressure**
When operating the photobioreactor make sure to not exceed the specified, maximum operating pressure (for OD 54 mm or 65 mm = 3 bar, for OD 100 mm = 2 bar). Note that the friction of the water flow increases with a square law dependence with the flow speed and therefore higher flow speeds may increase the inside pressure above tolerable levels. Prevent pressure bursts from the pumps.

**Temperature**
When the outside temperature drops below 0°C (32°F) the photobioreactor must be emptied. Freezing water inside the tubes will break the tubes.

**Inside cleaning procedure**
The tubes are made from chemically stable glass. They can be cleaned with various agents, as listed in the Technical Terms of Supply. In case of use of other agents than listed, please contact SCHOTT before use. Their chemical impact should not exceed the levels mentioned in the “Technical Terms of Supply”-brochure. When using a pig (cleaning sponge) make sure it is free from sand or similar abrasive agents to prevent scratching the inside of the tubes. Use sponges that are soft enough to move through the U-bends without getting stuck.

**Outside cleaning procedure**
When cleaning the outside do not use abrasives and make sure to not accidentally scratch the tubes with sand or similar agents attached to the surface.
For the outside cleaning as well as for cooling purposes of the PBR tubes, the use of demineralized water (< 1 µS) is strongly recommended to avoid the sedimentation of scale and other, which might reduce the transmission of the glass. Cleaning with demineralized water can be supported by high pressure washers. Please ask SCHOTT for release of your special set-up (distance to glass tube, max. allowed pressure, effective angle of spray nozzle, etc.). For already existing normal dirt & stains common household glass cleaners can be used.
In case of persistent contamination, the use of special adapted industrial cleaners may be required. The selected cleaner needs release of SCHOTT, in order to avoid any impact to the glass surface or coupling material.
PBR system/microalgae plant: ecoduna, Austria