SCHOTT
glass made of ideas

SCHOTT PBR
Installation and Operation Manual

Safety and Handling

Pioneering – responsibly – together. These attributes characterize SCHOTT as a manufacturer of high-tech materials based on specialty glass. Always opening up new markets and applications with a pioneering spirit and passion – this is what has driven the #glasslovers at SCHOTT for more than 130 years. Represented in 34 countries, the company is a highly skilled partner for high-tech industries: Healthcare, Home Appliances & Living, Consumer Electronics, Semiconductors & Datacom, Optics, Industry & Energy, Automotive, Astronomy & Aerospace. As a foundation company, SCHOTT has anchored responsibility for employees, society and the environment deeply in its DNA. The goal is to become a climate-neutral company by 2030.

With a production capacity of more than 230,000 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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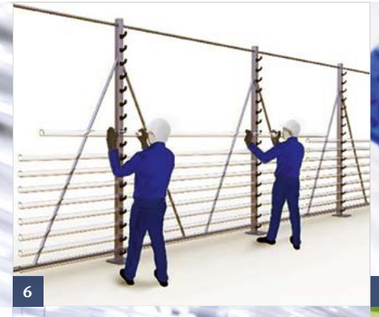
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Title
PBR system/microalgae plant:
Algalíf Iceland ehf., Iceland

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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!

1 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 in close proximity 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.

2 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.

3 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.

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

Handle glass with care!

5 SCHOTT recommends wearing goggles and work gloves during transport and handling of glass components and safety shoes when handling heavy glass components.

6 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.

7 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.

8 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.

9 SCHOTT recommends wearing safety goggles and work gloves when cleaning up broken pieces of glass.

PBR system/microalgae plant: Jongeruius ecoduna GmbH, 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.

Handle glass with care: Have the tubes laid into their position by two people.

Storage
SCHOTT products for algae cultivation must be stored in dry conditions in closed buildings. The floor must be level and horizontal and have a load-bearing capacity of 1,000 kg/m². Do not stack more than 3 pallets on top of each other. Only move unstacked!

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.

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:

	54 mm tube L = 5,500 mm	65 mm tube L = 5,500 mm	100 mm tube L = 3,850 mm
First support [mm] | [inch]	1375 | 54.1	1375 | 54.1	950 | 37.4
Unsupported middle [mm] | [inch]	2750 | 108.3	2750 | 108.3	1950 | 76.8
Second support [mm] | [inch]	1375 | 54.1	1375 | 54.1	950 | 37.4

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 8)*.

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

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.

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.

Thermal expansion [mm] | [inch]	54 mm tube L = 5,500 mm	65 mm tube L = 5,500 mm	100 mm tube L = 3,850 mm
ΔT = 20 °C = 36 °F	0.36 | 0.014	0.36 | 0.014	0.25 | 0.010
ΔT = 40 °C = 72 °F	0.73 | 0.029	0.73 | 0.029	0.51 | 0.020

Table 2: Thermally induced expansion of glass tubes at two exemplary temperature changes

For installation of the SCHOTT PBR Couplings, see Tutorial starting on page 9

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

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:

OD WT	54 mm tube 1.8 mm	65 mm tube 2.2 mm	100 mm tube 3.0 mm
Pressure [bar] [psi]	Force [N]	Force [N]	Force [N]
1 14.5	200	288	694
2 29.0	399	577	1388
3 43.5	599	865	2082

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}]: $3.3 \cdot 10^{-6}$

	54 mm tube L = 5,500 mm	65 mm tube L = 5,500 mm	100 mm tube L = 3,850 mm
Outer diameter, OD [mm] [inch]	54 2.13	65 2.56	100 3.94
Wall thickness, WT [mm] [inch]	1.8 0.071	2.2 0.087	3.0 0.118
Length [mm] [inch]	5,500 216.54	5,500 216.54	3,850 151.57
Inner volume [l] [gal]	10.97 2.90	15.86 4.19	26.72 7.06
Mass of empty tube [kg] [lb]	3.62 7.98	5.32 11.74	7.85 17.30
Mass of water filled tube [kg] [lb]	14.59 32.17	21.19 46.71	34.57 76.21

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

Installation of the SCHOTT PBR Couplings

A. Introduction

Watch the video!

This tutorial guide provides you with all the information that you need to successfully install your PBR couplings, open the couplings or replace the tubes. It begins with the tools and product types required, followed by a step-by-step guide includs additional information or assistance, please follow the link or QR code to watch our tutorial video.

B. Tools and Products

Required tools

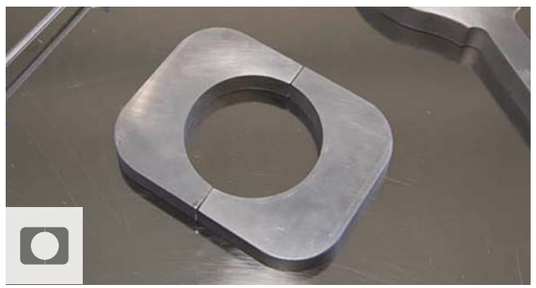
SCHOTT tool kit

The following tools are contained in the SCHOTT tool kit for the installation and dismantling of our tubular glass photobioreactor. There are two different tool kits available according to the coupling type used. The necessary tools for the particular instruction are depicted on top of each tutorial.

Defined value for torque:
Standard coupling 40 Nm
Slim Coupling 25 Nm

Torque Wrench (Standard coupling: 40 Nm, Slim Coupling: 25 Nm)

Jaw Wrench



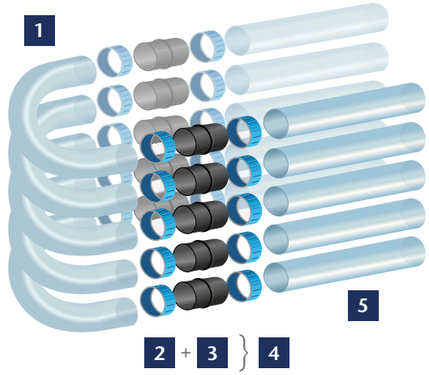
Coupling Opener

Dismantling Tool

Product range

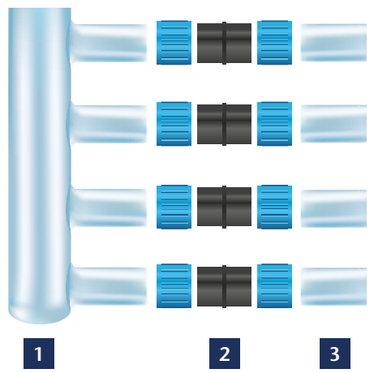
The SCHOTT couplings can be used for all PBR systems. All couplings types consist of one cage and two nuts – standard, slim, maintenance and adapter currently available for sizes 54 mm and 65 mm. 100 mm are available on request and depend on specific order quantities. See images below.

Helical System



1 U- or J-Bend
2 Nut
3 Cage
4 Coupling
5 Tubing

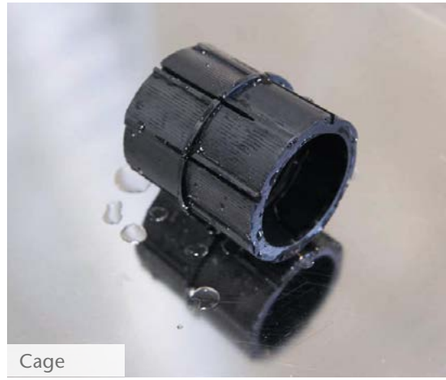
Fence System



horizontal or
vertical orientation

1 Manifold
2 Coupling
3 Tubing

Nut



Cage

Couplings

C. Instructions

Coupling installation

For a safe connection of the tubular glass parts you will need the torque wrench and the jaw wrench. These tools are used to tighten the couplings.

1 The connection of two tubes requires one coupling that consists of two blue nuts and one black cage.

2 Place the cages into warm water (approx. 50 °C / 122 °F) for a minimum of 15 minutes to allow an easier gliding of the cage over the tube end. The water will lubricate and expand the cage. Please do not use any other lubricants, such as oils or silicones.

3 After positioning the glass tubes slide the blue nuts over the adjacent tube ends. A correct orientation of the nuts is essential.

4 Now take the cage out of the water and push it over one tube end. It is essential to push the cage over the glass tube all the way to the spacer.

5 The other glass tube can now be pushed into the other end of the cage and both tubes are now in their final position. Push the nuts over the cage.

6 Take the correct torque wrench and place it on the left side of the coupling. Required torque for Standard Couplings is 40 Nm, for Slim Couplings it is 25 Nm. It is important to affix the draw-hook of the tool on the side averted to the body. Make sure there is enough space for the torque wrench to tighten.

7 The jaw wrench should be placed accordingly on the right side of the coupling.

8 Now turn the wrenches in opposing directions until the torque wrench tilts towards your body. The connection process is now completed.

9 Repeat these steps with all other couplings. For the connection of the tube levels please use the U-Bends. The installation of the couplings at the U-Bends is the same as shown before. First, affix two couplings to the U-Bend up to the spacers inside the cages.

10 Next push the U-Bend over two tube ends at the same time. Afterwards tighten the blue nuts as shown, before the U-Bend is fully mounted to the system.

C. Instructions

Coupling opening

For opening the couplings, the dismantling tool and the coupling opener are required. Please only use the provided tools for these steps.
Note: For opening do not reverse the installation process.
This will damage the coupling.

1 Assemble the coupling opener in the middle of the coupling and pull the nuts off the cage, see image on page 8. In case of difficulties with the dismantling the process can be assisted using a rubber mallet.

2 At this point, you may already be able to simply pull the tubes apart. If the tubes are difficult to remove from the cage, you can use the dismantling tool. Slip the nose of the tool into the slit of the cage and pry it open.

3 You can now pull one tube out of the cage and remove the cage from the other tube.

4 Finally wash all components with clean warm water so that they are ready to be reused or stored.

PBR system/microalgae plant: Algalíf Iceland ehf., Iceland

C. Instructions

Individual tube replacement

For this process, the dismantling tool, the torque wrench, the jaw wrench and the coupling opener are required. Please only use the provided tools for these steps.Note: Make sure to use the required torque depending on the coupling type:
Standard = 40 Nm, Slim = 25 Nm.

1 For the replacement of single tubes, you need to use a green maintenance coupling. The difference to the blue standard couplings is the missing spacer in the middle of the cage, that allows you to push the cage completely over the tube.

2 For replacing a tube you will need one standard coupling that is to be pushed over one end of the replacement tube.

3 Push the nut and the cage of the maintenance coupling completely over the other end of the new tube. Slide the other green nut over the end of the already installed tube.

4 Now take the tube and push the standard coupling at a very flat angle into the already installed tube of the system. Be sure to avoid glass to glass contact on the other end.

5 Now push the cage of the maintenance coupling half way over the other tube.

6 The gap between the tubes must be located in the middle of the coupling. You can now close both couplings with the provided tools.
Note: Make sure to use the required torque depending on the coupling type:
Standard = 40 Nm, Slim = 25 Nm

Operating Instructions

PBR system/microalgae plant: Jongerius ecoduna GmbH, Austria

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 borosilicate glass which is chemically resistant.
The elastomer of the couplings is EPDM, a material that is known for its high chemical stability which has been proven in the following conditions:

Agent	Chemical Formula	Concentration	Temperature	Duration
Citric acid	$C_6H_8O_7$	1 %	40 °C	50 days
Hydrogenperoxide	H_2O_2	6 %	40 °C	25 days
Sodiumhydroxide	NaOH	4 %	40 °C	20 days
Hydrochloric acid	HCl	3.6 %	40 °C	60 hours
Salt water	NaCl	4 %	40 °C	5 years

The couplings are stable under above conditions. Duration describes the continuous exposure in the given interval (1 day = 24 h).

The exposure of the coupling to a chemical agent may occur in several periods distributed over its lifetime. However, the overall exposure time and chemical impact must not be exceeded beyond the data listed in the above table. Please contact SCHOTT before you use other agents than listed.

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 accidently 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 others that might reduce the transmission of the glass.

Cleaning with demineralized water can be supported by high pressure washers. Please ask SCHOTT for approval 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 approval of SCHOTT, in order to avoid any impact to the glass surface or coupling material.

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SCHOTT North America, Inc., 2 International Drive, Suite 105
Rye Brook, NY 10573, USA

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