

Instruction Guide



PHOTOBIOREACTOR FMT150

Please read the Guide before operating this product



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The contents of this manual have been verified to correspond to the specifications of the device. However, deviations cannot be ruled out. Therefore, a complete correspondence between the manual and the real device cannot be guaranteed. The information in this manual is regularly checked, and corrections may be made in subsequent versions.

The visualizations shown in this manual are only illustrative.

This manual is an integral part of the purchase and delivery of equipment and its accessories and both Parties must abide by it.

TABLE OF CONTENTS

1	Warnings and Safety Precautions	5
2	General Description.....	6
3	Device Description.....	7
3.1	Configuration	8
3.1.1	Cultivation Vessel.....	8
3.1.2	LED Lighting	8
3.1.3	Thermoregulation	9
3.1.4	Measured Parameters	10
3.2	Standard Components	10
3.3	Control Unit Front Panel	12
3.3.1	LED Indicators	13
3.3.2	Digital Display on the Left	13
3.3.3	Display on the Right	13
3.3.4	Main Keys.....	13
3.4	Rear Panel of PBR FMT 150	14
3.4.1	Connector for pH/Temperature Sensor	14
3.4.2	Connector for O ₂ Sensor	14
3.4.3	USB PBR Communication Connector	15
3.4.4	AUX1 Connector	15
3.4.5	AUX2 Connector	15
3.4.6	USB TR Communication Connector	15
3.4.7	AUX3 Connector	15
3.4.8	AUX 4 Connector.....	15
3.4.9	Power Supply Connector	15
3.4.10	Identification Label with Serial Number	15

3.5	Connection Schema	15
4	Device Installation.....	16
4.1	Power Supply	16
4.2	Cultivation Vessel.....	17
4.2.1	Setup.....	18
4.2.2	Maintenance.....	19
4.2.3	Assembly.....	20
4.2.4	3000 ml Vessel Specifics	21
4.3	pH/Temperature Module	22
4.3.1	Installation	23
4.3.2	pH Calibration	23
4.4	Air Pump with Bubble Interruption Valve.....	24
4.5	Gas Supply.....	24
4.6	PBR Software	26
5	Optional Accessories/Components.....	27
5.1	O ₂ Module.....	27
5.1.1	Installation	27
5.1.2	Calibration.....	28
5.2	Digital CO ₂ Module	29
5.2.1	Installation	29
5.2.2	CO ₂ Sensor Calibration with iSense Software	30
5.2.3	CO ₂ Sensor Setting within PBR Control Software.....	31
5.3	Magnetic Stirrer	31
5.3.1	Installation	32
5.4	PWM Pump	34
5.4.1	Installation	35
5.5	Gas Mixing System GMS 150	35

5.5.1	Installation	36
5.6	Peristaltic Pump PP600	38
5.6.1	Installation	39
5.7	pH Stat Module	42
5.7.1	Installation	43
5.8	External Light Panel	45
5.8.1	Installation	45
5.9	Additional Software License	45
5.10	Light Upgrade.....	46
5.11	Supplementary/Replacement Components	46
5.11.1	Supplementary pH/T Probe	46
5.11.2	Additional Cable to Probes	46
5.11.3	Supplementary O ₂ Probe	46
5.11.4	O ₂ Membrane Kit	46
5.11.5	CO ₂ Membrane Kit	46
5.11.6	Supplementary Vessel (Standard Model)	46
5.11.7	Enhanced Vessel	46
5.11.8	Replacement Glass Window for Cultivation Vessel	46
5.11.9	Gasket Kit for Cultivation Vessel.....	46
6	Cultivation Guide.....	47
6.1	Set-up the Components	47
6.2	Set-up the Experiment	47
7	Appendix.....	49
7.1	FMT 150 Control Menu Tree.....	49
7.1.1	Control Keys and Used Symbols	49
7.1.2	Operation Schematic	50
7.1.3	Pulse Light Control	58

7.2	QY Measurement	59
7.3	Technical Specification Standards	60
8	List of Figures	61
9	Warranty Conditions	62

1 WARNINGS AND SAFETY PRECAUTIONS

PLEASE READ THE FOLLOWING INSTRUCTIONS CAREFULLY BEFORE TURNING THE PHOTOBIOREACTOR ON:

- Remove all packaging and transport protectors before connecting the Photobioreactor to the power supply.
- Use only cables supplied by the manufacturer.
- Keep the device dry outside and avoid working in high humidity environment!
- The manufacturer is not responsible for any damage due to improper operation!
- Water and other liquids should only be placed in vessels designed for the purpose and according to instructions included in this manual.
- Please keep the chamber, which holds the cultivation vessel, clean and dry. If water or cultivation media spills into the chamber, it may damage the equipment. The effect of salts on the heat exchanger at the bottom of the chamber (smooth metallic plate) can disrupt its surface and impair the thermal regulation.

GENERAL ELECTRICAL SAFETY GUIDELINES:

- Perform a routine check of the devices and their wiring.
- Replace worn or damaged cords immediately.
- Use appropriate electrical extension cords/power bars and do not overload them.
- Place the device on a flat and firm surface. Keep away from wet floors and counters.
- Avoid touching the device, socket outlets or switches if your hands are wet.
- Do not perform any alterations to the electrical parts of the device or its components.

The following table presents basic highlight symbols used in this manual:

Symbol	Description
	Important information, read carefully.
	Complementary and additional information.

Tab. 1 Used symbols.

	The Photobioreactor is considered Class 1M* LED Product. LED radiation may be harmful to eye. Avoid direct and strongly reflected exposure. Use protective glasses.
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**Class 1M: Laser and LED equipment that is safe for the naked eye under foreseeable conditions of operation. Looking directly into the source of radiation by employing optics within the beam, such as magnifying glass, telescope or microscope, can be potentially hazardous.*



2 GENERAL DESCRIPTION

Photobioreactor FMT 150 feature a unique combination of the cultivator and computer-controlled monitoring device. The Photobioreactor FMT 150 combines a cultivation vessel with the built-in fluorometer and densitometer. It is primarily designed for modular and precise phototrophic cultivation of algae, cyanobacteria and bacteria. Light power and spectral composition as well as temperature and aeration gas composition can be set with high accuracy.

User defined cultivation conditions can be dynamically varied according to user defined protocol. Continuous online monitoring of cultivation conditions and measured parameters is possible via the optional PBR software. Light, temperature, gas composition, and culture medium regime can be programmed to oscillate with various amplitudes and frequencies with user-defined time steps from seconds to hours via the software or via the control unit. Turbidostatic cultivation can be used for the stabilization of the suspensions via optical density control. In addition, up to 8 peristaltic pumps for different chemostat cultivation control can be linked to the Photobioreactor FMT 150 for the highly precise control of cultivation conditions.

The growth of the cultures is monitored by the integrated densitometer (OD720, 680 nm). Relative chlorophyll content of the culture can also be monitored continuously by the difference of optical densities at 680 and 720 nm. The instantaneous physiological state of the culture is measured by the Photosystem II quantum yield F_v/F_m .

The Photobioreactor FMT 150 has a flat-vessel design that enables uniform illumination over the whole culture. Photobioreactors are currently manufactured in three cultivation vessel capacities: 400 ml, 1000 ml and 3000 ml.

All Photobioreactor models may be supplied with a number of optional accessories – sensors, stirrers, pumps, etc. Control of the Photobioreactor is possible with either the control unit of the photobioreactor itself or the PBR software. However, the PBR software provides much wider functionality to define, control, display and analyze the experimental conditions and data.

3 DEVICE DESCRIPTION

Standard version of the Photobioreactor FMT 150 consists of a cultivation vessel with a sealable lid and a base box containing electronics circuitry, LED light panel (Fig. 1A) and other components essential for the optimal operation of the photobioreactor.

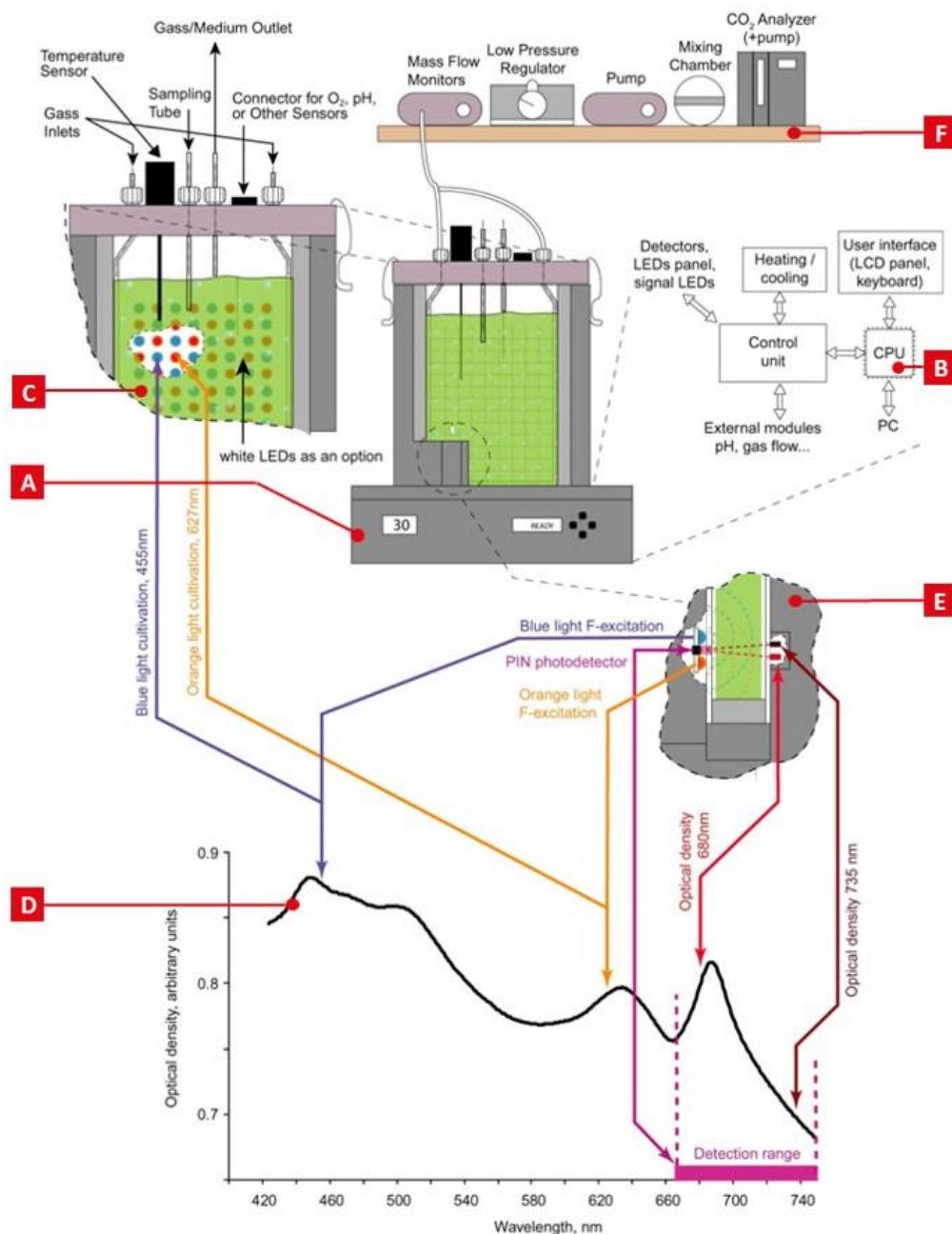


Fig. 1 Device description.

A) Photobioreactor body consists of a flat vessel holding the suspension and of a base box with electronic circuitry. B) The block scheme of the instrument shows the Control Processor Unit exchanging data and protocol with external computer (PC) and auxiliary external modules. The Control Unit governs measurements of parameters such as OD and chlorophyll fluorescence plus parameters measured by auxiliary sensors. It also controls the actinic light sources and temperature of the culture. C) Detail of the LED configuration. D) Uncorrected optical density spectrum of cyanobacterial suspension. The lines with arrows indicate wavelengths of various light sources that are integrated in the instrument. The detection range of the photodiode is also shown. E) Detail (rotated top to-bottom view) of the fluorometer and densitometer. F) Schematic representation of optional gas supply components and modules that can be used to stabilize aeration and set CO₂ concentration level.

The array of high-power light emitting diodes (LEDs) is located behind the cultivation vessel.

In the bottom corner of the front of the vessel is a semiconductor light sensor for measuring fluorescence emission and suspension optical density by attenuation of light that was emitted from the LEDs (Fig. 1E)

The Photobioreactor can also control external modules such as peristaltic pumps and solenoid valves via the photobioreactor control unit (shown schematically in Fig. 1F and Fig. 2). The solenoid valves are used to switch off the gas supply to the culture (bubbling) during optical measurements. Peristaltic pumps are used in turbidostat and chemostat modes to supply fresh medium or buffer.

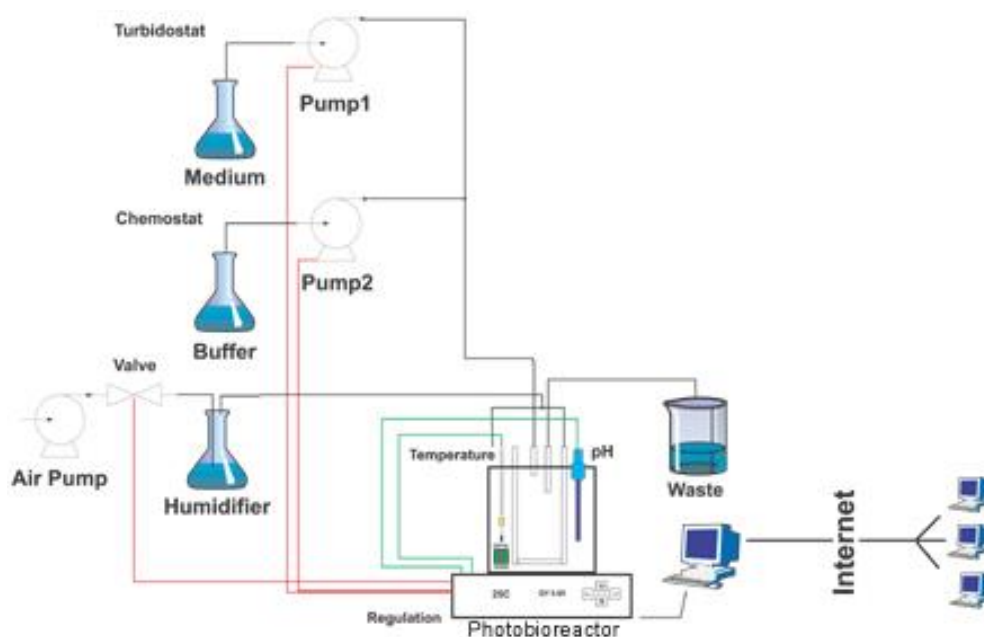


Fig. 2 Schematic diagram of the Photobioreactor, its modules and remote control.

3.1 CONFIGURATION

FMT 150 can be shipped with various configurations of vessel capacity, light quality, light intensity and thermoregulation. Numerous additional accessories such as various sensors can be supplied as described in chapter 5 on page 27.

3.1.1 CULTIVATION VESSEL

The cultivation vessel is flat and rectangular in shape. Its front and back windows are made of glass plates. The base is made out of stainless steel and contains a thermal bridge that facilitates heat transfer between a Peltier cell in the instrument base and the culture suspension. The lid of the vessel is easily detachable during cleaning and contains luer connectors for gas or medium supply tubing, waste medium exhaust or sample collection. The three larger ports accommodate the optional temperature/pH sensor and dissolved O₂ or CO₂ probes.

The Photobioreactor FMT 150 is manufactured in three vessel capacities enabling the customer to select optimal cultivation conditions for his experiments.

- 400 ml (in FMT 150/400)
- 1,000 ml (in FMT 150/1000)
- 3,000 ml (in FMT 150/3000)

3.1.2 LED LIGHTING

The high-power light emitting diodes generate a highly uniform irradiance flux that can be controlled in the range 0 – 3,000 $\mu\text{mol.m}^{-2}.\text{s}^{-1}$ PAR. The irradiance can be dynamically modulated by the FMT 150 control unit or by the PBR software. Spectra are shown in Fig. 3.

Two standard LED panel versions are available, each color is controlled independently:

- White-Red panel: maximum intensity 1,500 $\mu\text{mol.m}^{-2}.\text{s}^{-1}$ (white 750 / red 750 $\mu\text{mol.m}^{-2}.\text{s}^{-1}$)
- Blue-Red panel: maximum intensity 1,500 $\mu\text{mol.m}^{-2}.\text{s}^{-1}$ (blue 750 / red 750 $\mu\text{mol.m}^{-2}.\text{s}^{-1}$)

Two optional upgraded LED panel versions are available, each color is controlled independently:

- White-Red panel: maximum intensity $3,000 \mu\text{mol.m}^{-2}.\text{s}^{-1}$ (white 1,500 / red 1,500 $\mu\text{mol.m}^{-2}.\text{s}^{-1}$)
- Blue-Red panel: maximum intensity $3,000 \mu\text{mol.m}^{-2}.\text{s}^{-1}$ (blue 1,500 / red 1,500 $\mu\text{mol.m}^{-2}.\text{s}^{-1}$)

Optional customized panel versions:

- White-Blue: maximum intensity $1,500 \mu\text{mol.m}^{-2}.\text{s}^{-1}$
- White-Blue with Light Upgrade: maximum intensity $3,000 \mu\text{mol.m}^{-2}.\text{s}^{-1}$
- Red: maximum intensity $750 \mu\text{mol.m}^{-2}.\text{s}^{-1}$ (no light upgrade available)
- White: maximum intensity $1,500 \mu\text{mol.m}^{-2}.\text{s}^{-1}$
- White with Light Upgrade: maximum intensity $3,000 \mu\text{mol.m}^{-2}.\text{s}^{-1}$
- Blue: maximum intensity $1,500 \mu\text{mol.m}^{-2}.\text{s}^{-1}$
- Blue with Light Upgrade: maximum intensity $3,000 \mu\text{mol.m}^{-2}.\text{s}^{-1}$

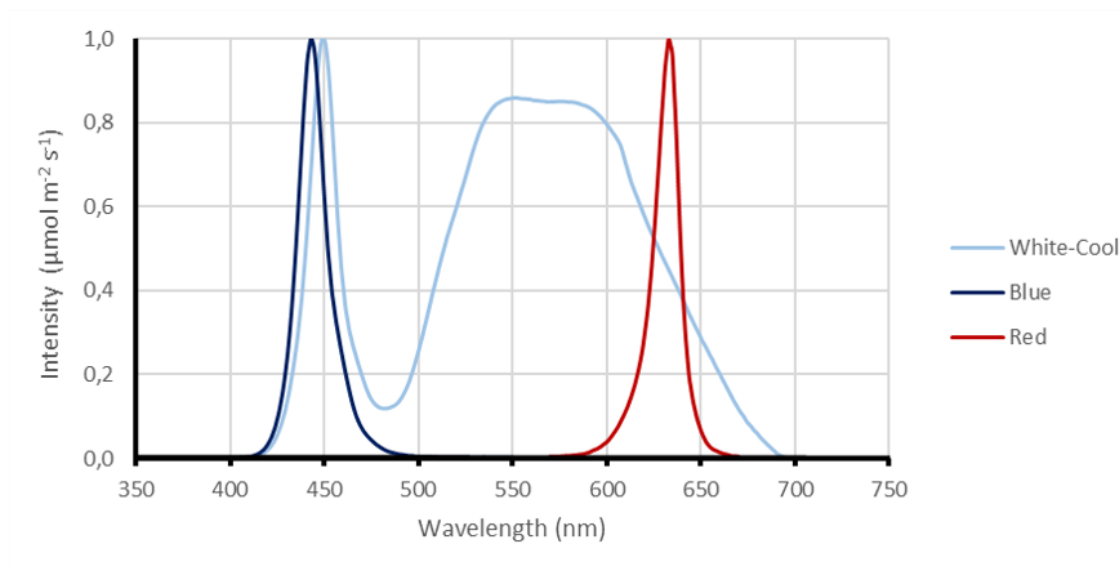


Fig. 3 LED spectra of PBR FMT 150.

3.1.3 THERMOREGULATION

It requires presence of the pH/Temperature probe.

Standard range (ambient temperature around 23 °C):

- 5 – 75 °C (FMT 150/400)
- 10 – 75 °C (FMT 150/1000 and FMT 150/3000)

Please find approximate estimation of time required for the given temperature equilibration in the Tab. 2 below.

Initial temperature	Target temperature	Light conditions ($\mu\text{mol.m}^{-2}.\text{s}^{-1}$)	Equilibration time required
5 °C	50 °C	1,500	2.5 hours
50 °C	5 °C	1,500	3 hours

Tab. 2 Temperature equilibration times.

3.1.4 MEASURED PARAMETERS

List of parameters measured and/or calculated by the Photobioreactor FMT 150:

Symbol	Name	Description
F_t (Dark)	Instantaneous fluorescence in the dark	Instantaneous F-yield in dark equals F_0 $F_t = F_0$ (in dark-adapted sample)
F_t (Light)	Instantaneous fluorescence in the light	Instantaneous F-yield in light that results from a dynamic equilibrium of plastoquinone reducing and re-oxidizing processes and from non-photochemical quenching $F_t = F_s$ (in light-adapted sample)
F_M (Dark)	Maximum fluorescence in dark-adapted state	Maximum F-yield with Q_A reduced ($q_P=0$) and non-photochemical quenching relaxed (NPQ=0)
F_M (Light)	Maximum fluorescence in light-adapted state	Maximum F-yield with Q_A reduced ($q_P=0$) and non-photochemical quenching active (NPQ $\neq$ 0)
F_V	Maximum variable fluorescence	$F_V = F_M - F_0$
QY (Dark)	Instantaneous PSII quantum yield in the dark	Effective PSII quantum yield $QY = F_V / F_M$ (dark-adapted sample)
QY (Light)	Instantaneous PSII quantum yield in the light	Effective PSII quantum yield relaxing in light $QY = F_V' / F_M'$ (light-adapted sample)
OD_{680}	Optical density at 680 nm	Optical density representing light scattering and chlorophyll absorption.
OD_{720}	Optical density at 720 nm	Optical density representing light scattering.
pH	pH	pH is the negative logarithm of the hydrogen ion concentration in the medium.
$[O_2]$	Oxygen concentration	Concentration of dissolved oxygen.
$[CO_2]$	Carbon dioxide concentration	Concentration of dissolved carbon dioxide. CO_2 partial pressure is calculated using the measured pH and the temperature.

Tab. 3 FMT 150 measured parameters.

3.2 STANDARD COMPONENTS

Photobioreactor FMT 150 can be purchased in different configurations from minimal up to complex system consisting of numerous accessories linked together. They can be controlled via the Photobioreactor control unit itself or by the PBR software for full operation of the system. However, the Photobioreactor control unit offers only static manual control.

Minimal required configuration that is recommended to be purchased for optimal operation of the Photobioreactor cultivation and monitoring system consists of set of standard photobioreactor components (as listed below) plus air pump with bubble interruption valve and pH/temperature module. Optional components that are available as accessory modules and can be purchased together with Photobioreactor FMT 150 are described in chapter 5.

Photobioreactor FMT 150 purchased in minimal configuration can be effectively used for cultivation and monitoring purposes, however without purchasing PBR software no measured data can be stored and visualized as well as no user-defined protocols can be designed. Chapter 3.3 and chapter 7.1 describe how to operate the PBR FMT 150 in cultivation mode via front panel control unit, without use of PBR software.



Customers are kindly asked to check the contents of the delivered package and compare it with enclosed package list generated based on customer's order. Please contact the support@psi.cz if any discrepancies occur.

Minimal configuration of the FMT 150 is shipped with:

1. Power supply with the power cord.
 2. Photobioreactor with integrated double-modulation fluorometer – Ft, Fm, QY and integrated optical density measurement.
 3. Cultivation vessel with capacity 400 ml (with holder) for FMT 150/400, 1000 ml for FMT 150/1000 or 3000 ml for FMT 150/3000.
 4. LED panel shield.
 5. Spare Part Kit* – for the complete list of Spare Part Kit see Tab. 4 on page 12 and corresponding Fig. 4.
 6. User guide (this document) and Software manual.
 7. Bubble Humidifier – to maintain stable culture volume.
- Components #8 and #9 below are highly recommended for proper functionality of the PBR, but are not included in the standard configuration and have to be purchased separately.
8. Bubble interruption valve with air pump.
 9. pH/temperature module.

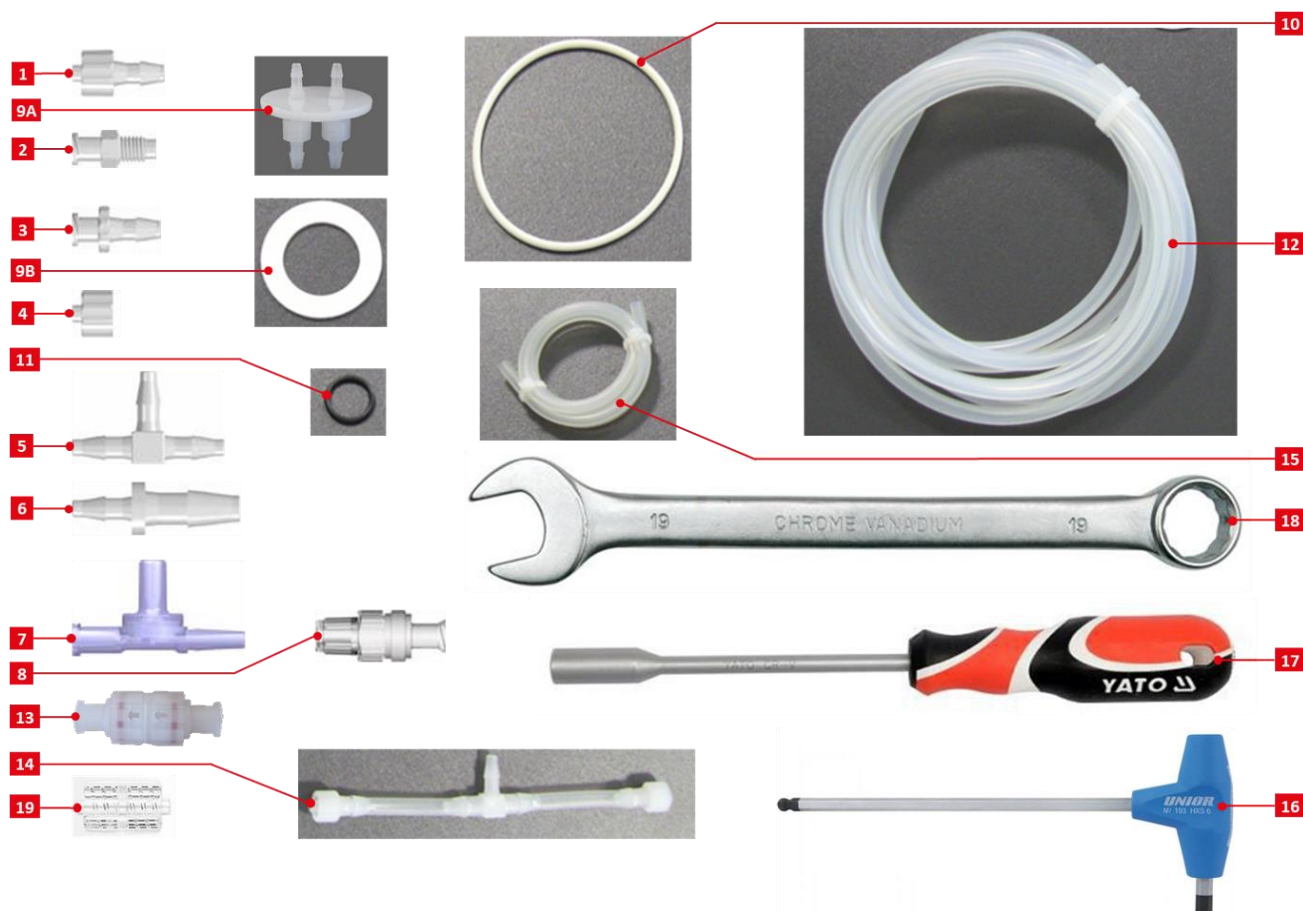


Fig. 4 Components of the Spare Part Kit.

Numbers correspond to component number in Tab. 4.

Component Number	Component Description	Specification	Explanation	Pcs
1	Male Luer Integral Lock MTLL240-J1A*	5/32" (4.0 mm)		10
2	Female Luer Thread Style BSFTLL-J1A*	5/16" Hex to 1/4-28 UNF Bottom Sealing Thread	For fixing of stainless tubes in the cuvette's lid. The fittings are modified - drilled with 3 mm drill bit	10
3	Female Luer Thread Style FTLL240-1*	5/32" (4.0 mm)		10
4	Male Luer Integral Lock Ring Plug LP4-J1A*			10
5	Tee Tube Fitting T40-J1A*	5/32" (4.0 mm)		10
6	Reduction Tube Fitting 4060-1*	1/4" (6.4 mm) and 5/32" (4.0 mm)		5
7	Double Check Valve DCV118-001*		Safety valves that permit gases and liquids to flow in only one direction	5
8	Check Valve SCV08053*		Check valve for with low priming volume	5
9	Plastic lid with ports (9a) with silicone ring (9b)	Silicon ring 27x42x2 mm	For humidifier bottle	1+2
10	O-ring	75x3 mm	Sealing between lid and the vessel	5
11	O-ring	14x2 mm	Sealing to the openings for optional sensors	10
12	Silicon Tubing	Ø 6/3 mm	Additional tubing	10 m
13	Pressure relief valve	0.083 bar	Release overpressure from the vessel	5
14	T-tube (silicone tubing with 2 pcs of Male Luer Lock and 1 pc of Tee Tube Fitting)		Aeration tubing for the vessel	1
15	Silicone tubing	Ø 5/2 mm	Additional tubing	0.5 m
16	Hex Key	5 mm	To loosen up the screws of the lid	1
17	Spanner/Screwdriver	8 mm	For releasing filler screws in optional sensor positions and luer connectors in the vessel lid	1
18	Wrench	19 mm	For releasing sensors	1
19	Male to Male Luer Connector	5/32" (4.0 mm)	Reduction between pressure relief valve and cultivation vessel	5

Tab. 4 List of Spare Part Kit – components shown in Fig. 4.

* Provided by: www.valueplastics.com

3.3 CONTROL UNIT FRONT PANEL

Photobioreactor Control Unit front panel can be used for simple manual control of the PBR FMT 150. By using the keys on the front panel, the operation of cultivation and monitoring units such as pH/temperature sensor, light control, OD monitoring module, PWM mode or CO₂ and O₂ sensor can be controlled. When FMT 150 photobioreactor is purchased without the Remote Control System for PBR FMT 150 then all of the control has to be set up manually using the front panel of the FMT 150 control unit. The user can read out from the display the actual values for the given sensor or monitoring unit.



Please note that no user-defined protocols can be designed and no data recording is possible without the PC and PBR software.
Please note that neither turbidostat nor chemostat module can be operated if FMT 150 is purchased without the PBR software.

The front panel of the FMT 150 control unit has 4 LED lights on the left and 5 control keys on the right (Fig. 5).

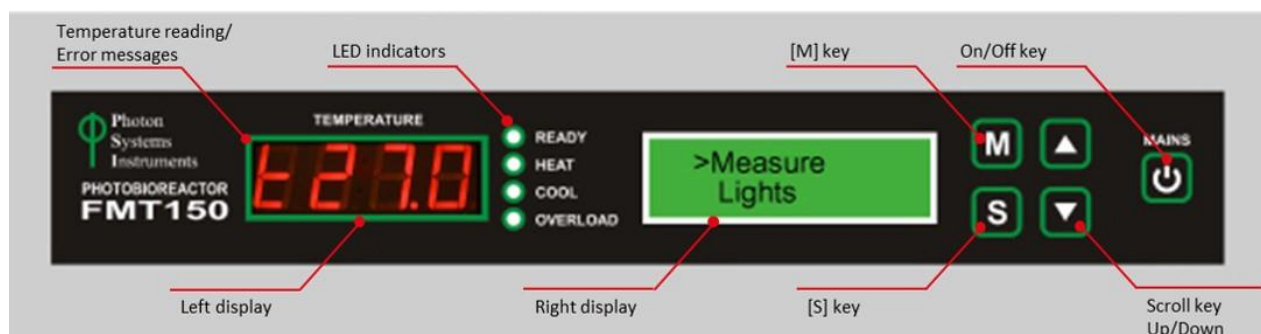


Fig. 5 Photobioreactor front panel.

3.3.1 LED INDICATORS

Green LED indicator **READY** is lighting when the current temperature is equal to target temperature.

Orange LED indicator **HEAT** is lighting when the heater turns on in the cultivation vessel.

Blue LED indicator **COOL** is lighting when the water in the cultivation vessel is cooled and the Cooling Unit is operating. The minimal temperature in the standard PBR FMT 150/400 is 5 °C.

Red LED indicator **OVERLOAD** is lighting when the requested temperature in the cultivation vessel higher than the current temperature was not reached yet.

3.3.2 DIGITAL DISPLAY ON THE LEFT

Displays the current temperature in the cultivation vessel and error messages if any problems with the FMT 150 occur. Possible error messages are:

- Er6 – Temperature/pH sensor is not connected.
- Er7 – Temperature sensor is not functional and must be repaired. Please contact support@psi.cz if this error occurs.

3.3.3 DISPLAY ON THE RIGHT

This display shows various functions of the FMT 150 and these are activated and set with the main keys on the right side of the control unit as described below.

3.3.4 MAIN KEYS

[M]: Used to move back in the menu tree or to exit the menu.

[S]: Used to move forward in the menu tree, to save the selection, or to turn ON/OFF.

[▲]: Used to move up in the menu or to add value.

[▼]: Used to move down in the menu or to subtract value.

[Mains]: (On/Off) key doesn't have any function related to the common use of PBR and it is intended only for service purposes. The Photobioreactor is turned on by switching on the corresponding Power supply.



Please refer to the chapter 7.1 if Photobioreactor FMT 150 is purchased without the PBR software and the PBR FMT 150 is to be controlled solely manually via the control unit front panel.

3.4 REAR PANEL OF PBR FMT 150

The rear panel houses connectors for all connecting cables (Fig. 6). Please note that the numbers in the next section correspond to the numbers in Fig. 6.

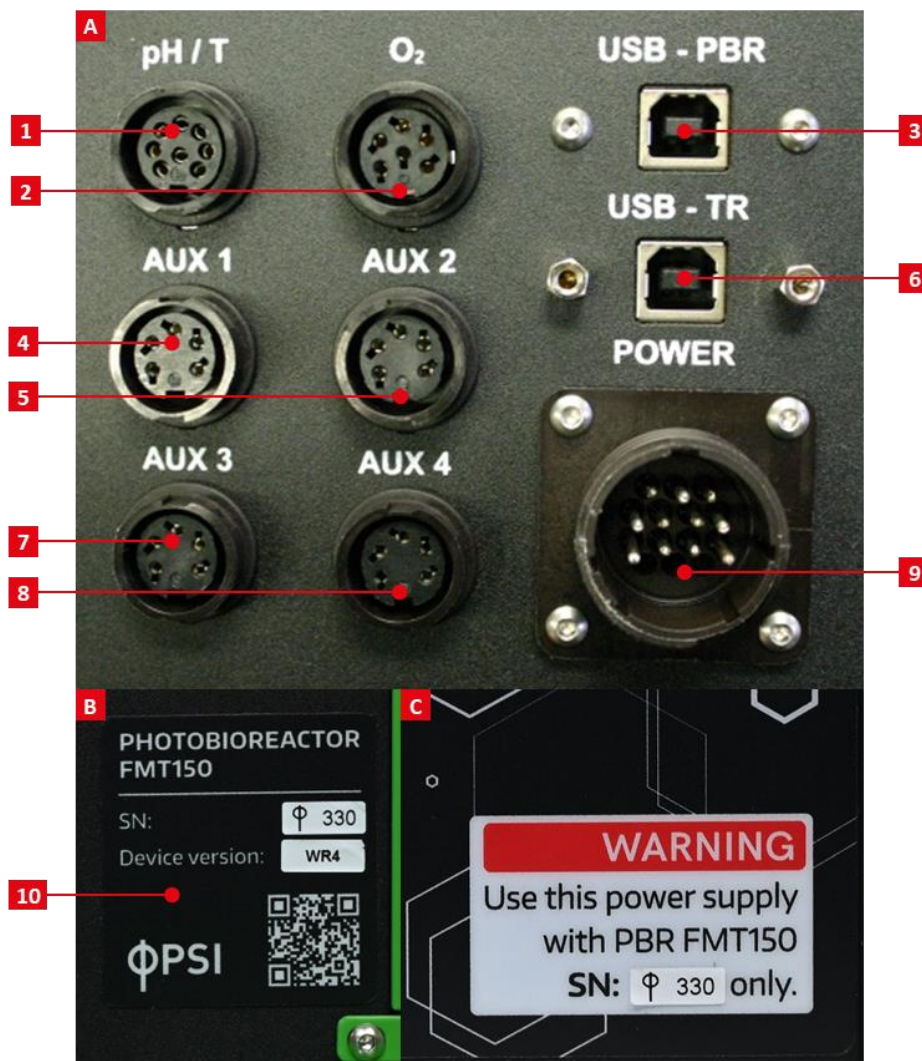


Fig. 6 PBR FMT 150 control unit and its power supply rear panel.

A) Back panel of the Photobioreactor control unit. B) Serial number on the front panel of the PBR FMT 150 unit. C) Rear panel of the power supply with the serial number (red arrow).

3.4.1 CONNECTOR FOR pH/TEMPERATURE SENSOR

pH/temperature sensor should be plugged to this connector when in use. PBR FMT 150 control unit recognizes when the sensor is connected and will automatically control the operation of the sensor.

3.4.2 CONNECTOR FOR O₂ SENSOR

O₂ sensor should be plugged to this connector when in use. PBR FMT 150 control unit recognizes when the sensor is connected and will automatically control the operation of the sensor.

3.4.3 USB PBR COMMUNICATION CONNECTOR

USB communication cable is provided as part of the PBR FMT 150 package when purchased with the Remote Control System to connect the PBR FMT 150 with the computer. This connection has to be made for the communication of the PBR FMT 150 via the PBR software.

3.4.4 AUX1 CONNECTOR

AUX1 connector should be used for the CO₂ sensor, peristaltic pump, PWM pump, additional light or magnetic stirrer (please see Fig. 7 on page 16 for detail description of possible connection schemes).

3.4.5 AUX2 CONNECTOR

AUX2 connector should be used primarily for the bubble interruption valve but can be also used for CO₂ sensor, peristaltic pump, additional light (please see Fig. 7 on page 16 for detail description of possible connection schemes).

3.4.6 USB TR COMMUNICATION CONNECTOR

USB TR communication connector is designed only for servicing the FMT 150 thermoregulator by the manufacturer.



NEVER USE THE USB TR CONNECTOR WITHOUT PRIOR CONSULTATION WITH THE MANUFACTURER.

3.4.7 AUX3 CONNECTOR

AUX3 connector is additional connectors that can be used for the CO₂ sensor, peristaltic pump, additional light.

3.4.8 AUX 4 CONNECTOR

AUX4 connector is additional connectors that can be used for the CO₂ sensor, peristaltic pump, additional light.

3.4.9 POWER SUPPLY CONNECTOR

The power supply unit is plugged into the FMT 150 control unit via this connector.

3.4.10 IDENTIFICATION LABEL WITH SERIAL NUMBER

Each Photobioreactor FMT 150 has a serial number that corresponds with the serial number of the power supply unit. These are always provided together and are not interchangeable. Prior to switching PBR FMT 150 device ON make sure that the serial number on the front panel of the main body matches the serial number on the power supply (Fig. 6C).



Damage can occur when the power supply is incompatible with the PBR FMT 150 device.

3.5 CONNECTION SCHEMA

Depending on the use of optional modules and the set-up of the PBR FMT 150, the connection schema for the optional and standard modules with the PBR FMT 150 control unit rear panel may differ. Please refer to Tab. 5 below to see the possible order of connecting the different modules to the PBR FMT rear panel.

Devices for which the interconnection is possible can be connected together in a series by AUX IN and AUX OUT connectors according to the recommended order. Please refer to Fig. 7 for recommended schematic connection setup for all available modules and accessories.

Device used	Proper connector	Device interconnection possible
Magnetic Stirrer	AUX 1	NO
PWM Pump	AUX 1	NO
Bubble Interruption Valve	AUX 2	NO
Peristaltic Pump	AUX 1/2/3/4	YES

CO ₂ module	AUX 1/2/3/4	YES
External Light	AUX 1/2/3/4	YES

Tab. 5 External connectors.



Please note that Bubble Interruption Valve must be always connected to the AUX2 connector and Magnetic stirrer and PWM pump always to connector AUX1. In case of magnetic stirrer and PWM Pump, only one of the two devices can be connected to the PBR FMT 150 at one time.

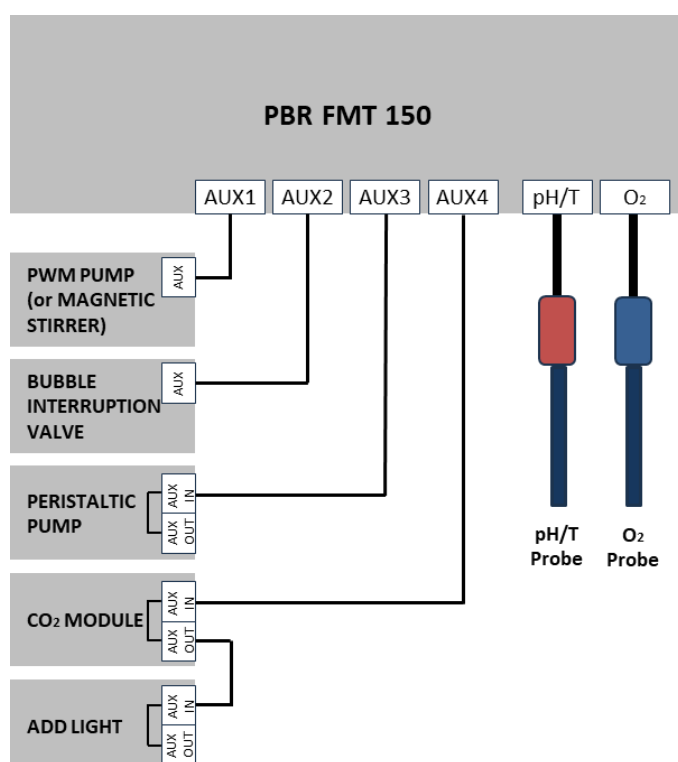


Fig. 7 Schematic of recommended set-up for interconnecting available modules with PBR FMT 150 control unit.

4 DEVICE INSTALLATION

To install the device properly, it is necessary to follow the proper sequence of the assembly instructions. Instructions for assembly of standard PBR FMT 150 (400, 1000 and 3000 ml) are described below.

4.1 POWER SUPPLY

- Make sure that the power supply is switched OFF.
- Connect the thick power cord of the power supply to the round Power connector at the rear panel of the Photobioreactor (Fig. 8).
- Plug the AC power cord into an electrical outlet (Fig. 8B,C).
- Switch on the power supply.



It is necessary to allow 20 minutes stabilization time for the device prior any experiment or calibration is performed. This stabilization time is required for temperature stabilization of the measuring system. It is strongly recommended to use back-up UPS system to protect the PBR FMT 150 system from power outage. If UPS system is not used and the AC power is turned off unexpectedly the PBR FMT 150 control unit will

automatically switch ON after the AC power is restored again and no manual action is required. Please note that if PBR software is used and the power outage occurred all previous settings will be restored and the currently running experiments will continue.



Fig. 8 Connection of the Photobioreactor and the power supply.

1) and 3) Power cord connection. 2) ON/OFF key.

4.2 CULTIVATION VESSEL

The standard cultivation vessel has capacity of 400 ml, 1000 ml or 3000 ml (depending on the unit ordered). It is made from flame proof glass (thickness 3.3 mm), stainless steel (AISI316L), duralumin with black eloxal coating, silicone sealing, and Lukopren S6410T glue. Each vessel is tested and autoclaved (20 minutes at 120 °C) by the manufacturer before distribution.

Volume	Weight	Dimension
400 ml	2.8 kg	23.88 × 3.70 × 19.3 cm
1000 ml	3.8 kg	23.88 × 7.36 × 19.3 cm
3000 ml	6.2 kg	31.70 × 7.36 × 30.3 cm

Tab. 6 Weights and dimensions.

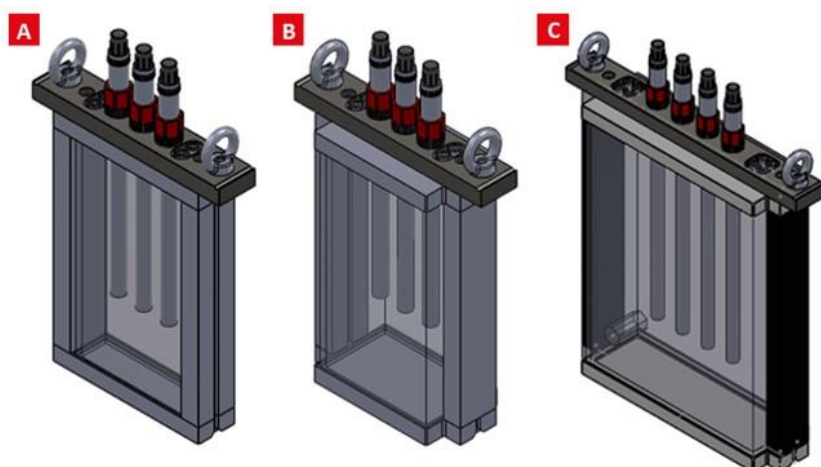


Fig. 9 Schematic design of the PBR cultivation vessel types.

A) Vessel for PBR FMT 150/400. B) Vessel for PBR FMT 150/1000. C) Vessel for PBR FMT 150/3000.

4.2.1 SETUP

The lid of the vessel is fastened to the vessel via two screws (n°3 in Fig. 10C) using the hex key provided. The lid has two holders built in for easy handling of the vessel in and out of the photobioreactor (n°2 Fig. 10C). There are four openings for luer connectors. These are used for connection of aeration tubing, sampling tubing, waste expel tubing and pressure relief valve (Fig. 10B). The lid also has three larger openings for optional sensors such as pH/Temperature, O₂, CO₂ probes. If sensors are not used these openings can be kept closed with the filler screws provided.

The stainless-steel aeration tubing mounted to the bottom of the vessel lid is connected via two Luer Lock connectors with the gas dispenser tubing (n°4 in Fig. 10A) linked via a T-piece to the humidifier bottle (Fig. 10B). The source gas for the culture (gas pump or gas mixing system) is humidified before entering the culture vessel and this helps to maintain a constant volume in the vessel. The third luer lock connector is linked with silicone tubing (n°7 in Fig. 10A,C), which serves for removal of residual or overflow medium.



The longer metal thin tubing on the vessel lid is used for medium outlet.

The fourth luer outlet can be either closed by a Lock Ring Plug (component n°4 in Tab. 4) or connected with silicone tubing and used as a sampling outlet or for medium in-flow when connected with peristaltic pump (n°6 in Fig. 10A,C).

Once the cultivation vessel is set up and placed in the photobioreactor it should be locked to the body of the PBR FMT 150 by the clips on each side of the PBR.

To avoid over-pressurizing and bursting of the cultivation vessel, a pressure relief valve can be connected to the lid. Depending on the setup, the relief valve can be connected in the empty luer connector via a Male-to-Male reduction (Fig. 10B) or in the aeration tubing via Male Luer Integral Lock with T-connector (Fig. 10C). The arrows on the valve indicate the direction of air release. The valve must be connected to a connector that leads into the headspace and not into the fluid. All components belonging the overpressure kit (pressure relief valve, reduction, luer connectors) are autoclavable.



The pressure relief valve prevents rupture of the cultivation vessel. The pressure relief valve must be connected in the proper orientation (with arrows pointing upwards - Fig. 10B,C) to a connector that leads into the air (into the headspace of the cultivation vessel).

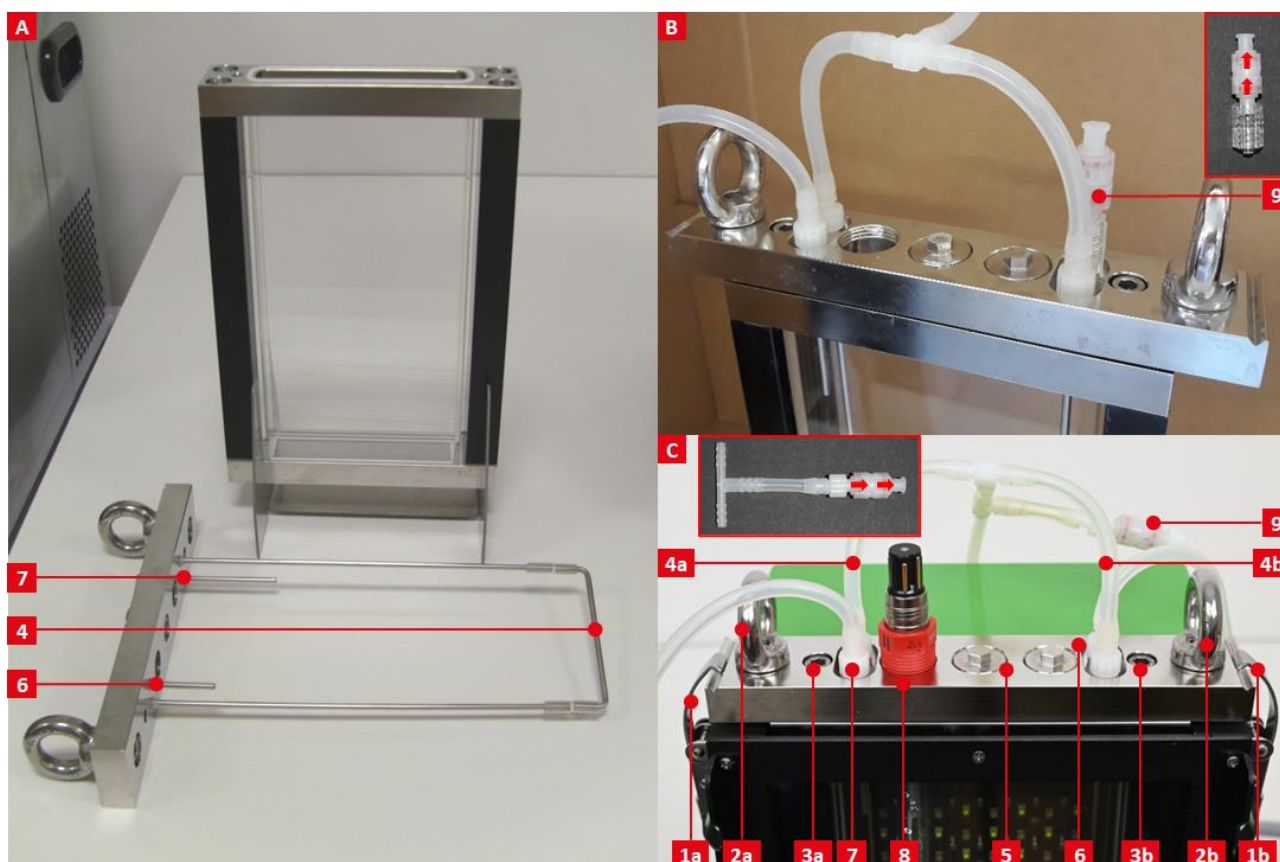


Fig. 10 Components of the 400 ml cultivation vessel.

A) vessel and the vessel lid; numbers correspond to description in C. B) Top of the lid with connection of the aeration tubing. C) Vessel lid with one sensor and all tubing connections: (1a,b) Clips to lock the vessel to the PBR. (2a,b) Holders for easy vessel manipulation. (3a,b) Screws for fastening part to the lid to the vessel. (4a,b) Inlets for the gas dispenser tubing. (5) Connectors for optional sensors closed with filler screws. (6) Sampling tube. (7) Excess medium outlet. (8) pH/temperature sensor. (9) pressure relief valve.



Please note that if the vessel is removed in 1000 ml or 3000 ml version of the PBR FMT 150, calibration constants stored in the system after OD calibration will no longer correspond to the new conditions. In 1000 ml or 3000 ml PBR FMT 150 version glass tunnel is used to improve optical path for OD and fluorescence measurements, therefore any shift in the position in the vessel might slightly change the optical path of the measuring beam and influence the absolute measured values. Please refer to the OD calibration procedure for detail information.

4.2.2 MAINTENANCE

The whole vessel is fully autoclavable, including the detachable lid, connectors, sensors, and silicone tubing. However, keep in mind that most materials deteriorate after repeated autoclaving. We recommend that you keep autoclaving to a reasonable minimum. For most cases, hot water (60 – 70 °C), standard detergent and thorough mechanical cleaning are enough to keep the equipment clean and non-contaminated. Optionally, the vessel and all the tubings can be disinfected with 70% ethanol. When cleaning the cuvette, it is very important to rinse off any residue of detergent or medium and to dry the cuvette with a soft cloth – this will help to prevent the cuvette corrosion. The cuvette should not come in contact with strong acids or acid vapors.

The O₂ sensor and pH sensor may be autoclaved or sterilized up to 140 °C; the CO₂ sensor may be autoclaved or sterilized up to 130 °C.

4.2.3 ASSEMBLY

The next instructions describe cultivation vessel assembly:

- Remove the lid from the vessel by loosening the two screws with the provided hex key.
- Fill the vessel with medium, place the stir bar inside the vessel if used with the magnetic stirrer.
- Prepare the gas dispenser tubing by connecting the T-piece (n°14 in Tab. 4) with longer silicone tubing. Connect the gas dispenser tubing to the two luer connectors as shown in Fig. 11A,B.



Standard version of the PBR FMT 150 is connected according to the Fig. 10B, when optional modules such as peristaltic pump or GMS are used see page 35 and 38 for further instructions.

- Close the last Luer Lock connector with the Luer Lock Ring Plug (n°4 in Tab. 4).
- Re-attach the lid to the vessel Fig. 10C-3) using provided hex key. Make sure that the rubber gasket between the vessel and the lid is properly installed and a good seal is achieved.
- If needed, autoclave the assembled vessel.



Never close all three sensor holes with the screws during autoclaving. It is recommended to leave one sensor hole empty and cover the lid completely with aluminium foil to prevent pressure build-up during autoclaving and keep the vessel protected from any contamination prior experiment initiation. Provided sensors such as pH/temp, O₂ and CO₂ probes can be autoclaved but their lifetime is reduced by repeated autoclaving.

- Insert the assembled and prepared vessel into the Photobioreactor and lock it using the metal clips (Fig. 10C-1).



For detail description of recommended protocol for initiation of cultivation for algae and cyanobacteria in PBR FMT 150 please refer to chapter 6 on page 47.

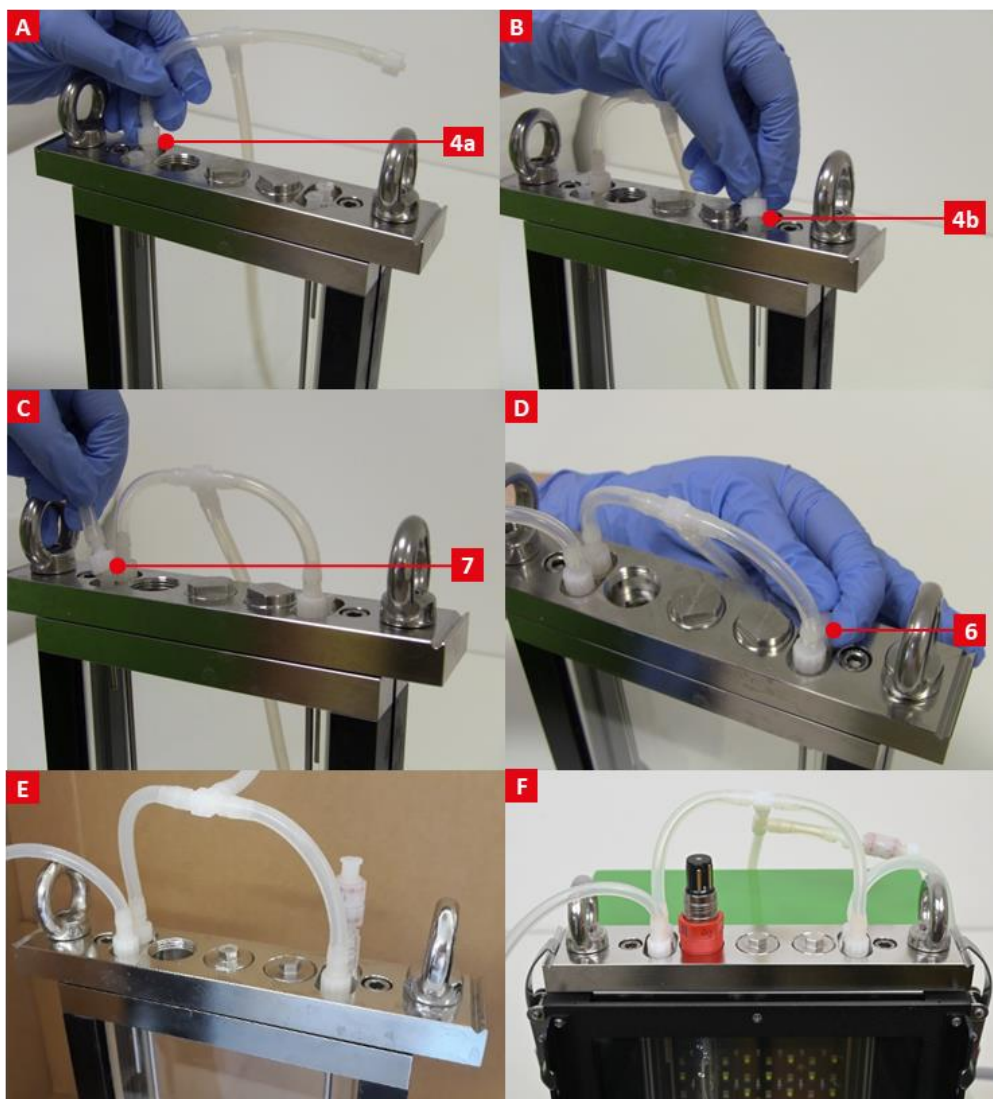


Fig. 11 Assembly of the vessel lid.

A-D) Individual steps of standard vessel assembly set-up are shown. The numbers correspond to numbers in Fig. 10C.

4.2.4 3000 ML VESSEL SPECIFICS

The PBR FMT 150/3000 provides more connectors than in 400/1000 ml models to give the user broader range of connected optional instruments and larger scope of operational features.

Please refer to Fig. 12 for detail description of the 3000ml vessel lid and all the connectors:

- (2) Holders for easy vessel manipulation.
- (3) Screws for fastening part of the lid to the vessel.
- (4) Inlets for the gas dispenser tubing.
- (5) Connectors for optional sensors closed with filler screws.
- (6) Sampling tube for turbidostat mode. Inlet is used to add medium to the vessel or to collect the samples.
- (7) Excess medium outlet.
- (9) Inlets for chemostat mode. Inlets for base and acid chemostat mode.
- (10) Optional inlets (e.g. for multiple peristaltic pump connection).

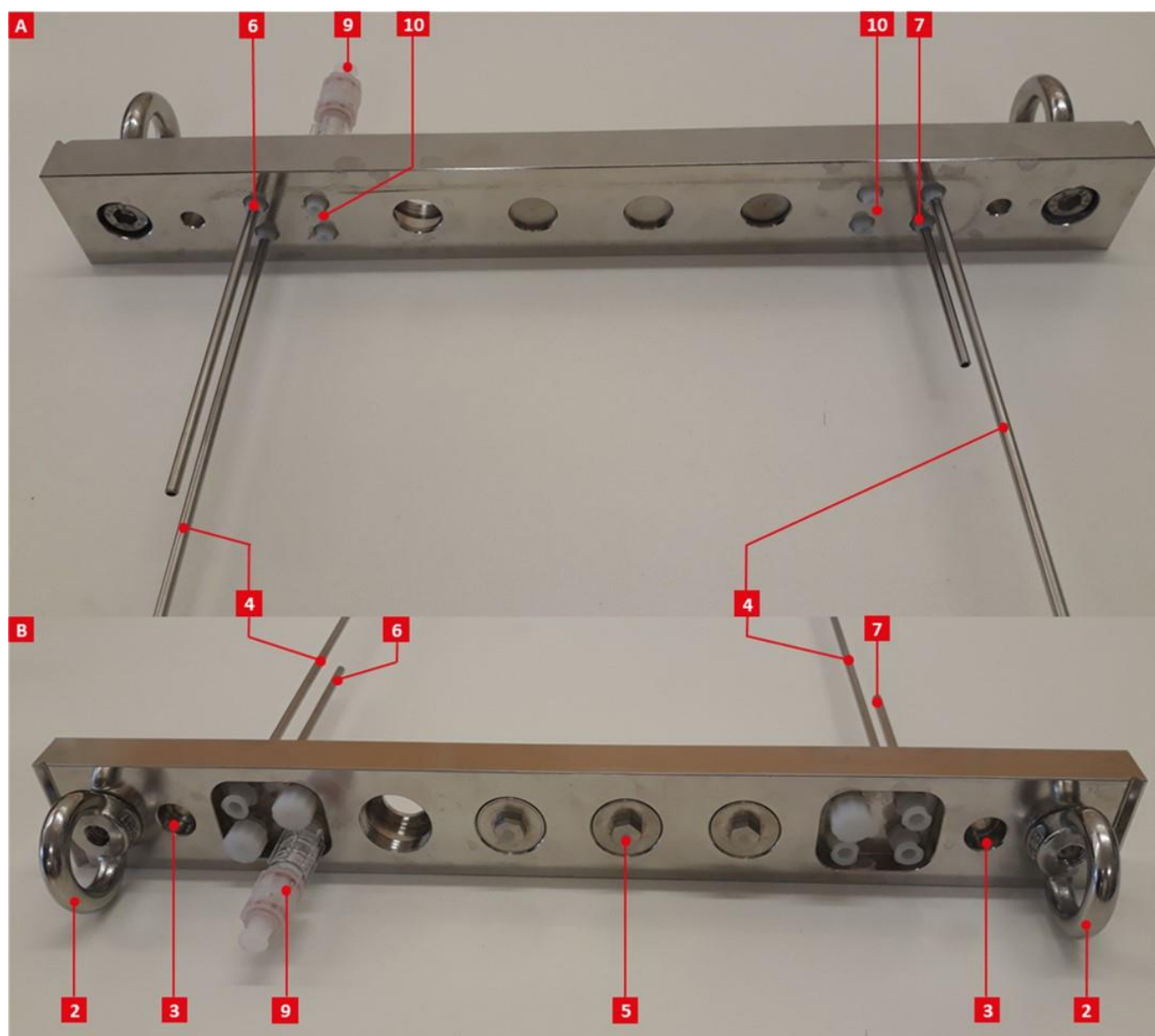


Fig. 12 Components of 3000 ml cultivation vessel.

4.3 pH/TEMPERATURE MODULE

The pH/temperature module is designed for continuous measuring of pH and temperature in the medium. pH/temperature sensor is part of minimal required configuration (described in chapter 3.2).

The module consists of electronic unit embedded in Photobioreactor FMT 150 Control Unit, probe and communication cable (Fig. 13).



InPro3253SG/120/PT1000 single rod measuring cells from METTLER TOLEDO (www.mt.com) are supplied as low maintenance, autoclavable and pressure resistant pH electrodes with a factory filled pre-pressurized liquid electrolyte and a reference electrolyte together with a silver ions barrier. Measurement disturbances caused by earth potentials are avoided through employment of a “solution ground” option available with InPro3250SG version. For more information, please refer to manual provided by electrode manufacturer.

Fig. 13 pH/temperature module.



It is strongly recommended to avoid autoclaving pH electrode. The manufacturer states that autoclaving deteriorates it rapidly. Use warm water with a detergent or chemical disinfectant for its cleaning.

4.3.1 INSTALLATION

- Insert the pH electrode into the open port and secure it tightly with a plastic ring around the probe (Fig. 14A,B).
- Note:** Any position in the lid can be selected for the pH/Temperature sensor. However, we recommend placing the O₂ sensor in the far right connector of the vessel, where magnetic stirrer provides most homogeneous mixing of the media.
- Attach the cable labeled “pH” to the pH/Temperature electrode (Fig. 14C).
 - Connect the connector cable with the PBR FMT 150 (Fig. 14D).
 - When connected to the PBR FMT 150 control unit, sensor unit is automatically recognized. The function of the pH/temperature sensor can be controlled manually by the front panel of the control unit and remotely via PBR software. For manual control please refer to control menu tree on page 49 for more detail explanation.

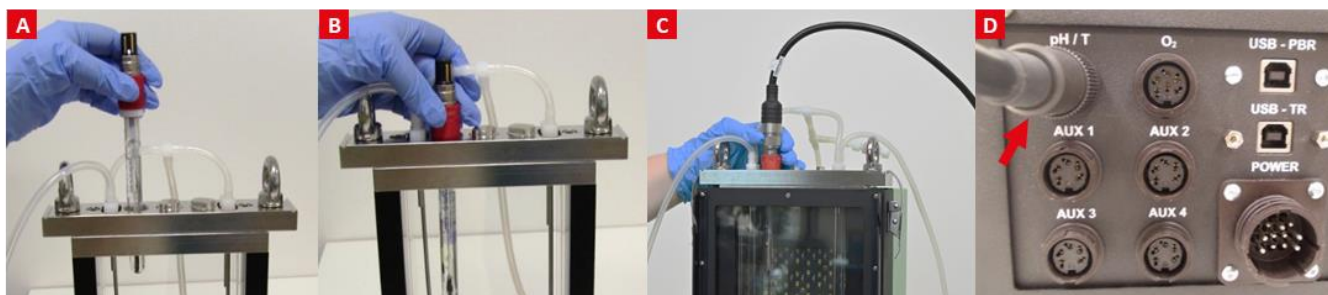


Fig. 14 Installation of the pH/temperature sensor.

A) Positioning the probe. B) Securing the probe. C) Attaching the cable to the positioned probe. D) Attaching the cable to the rear side of the PBR.

4.3.2 pH CALIBRATION

Prior to initiation of each experiment, it is recommended to perform the pH sensor calibration. The calibration can be done either in PBR software (for more details see PBR Software manual) or using the FMT 150 control unit front panel as described below.

Follow these instructions during calibration:

- Go to operation menu using the front panel of the PBR control unit. In the operation menu go to Setting > Calibration > Calibration pH.
- Place the pH sensor connected to the PBR in pH = 7 buffer calibration solution (Fig. 15A).



Please note that the calibration solutions are not provided by the manufacturer.

- Read the signal value on the display of the photobioreactor control unit (Fig. 15B), wait until it is stable and confirm this value by pressing the “S” key.
- Repeat the same procedure with buffer solution of pH = 10.
- When calibration is done, press the “M” key to get back to the main menu.
- Optional: Calibration accuracy may be verified by plunging the electrode in the same calibration solutions of known pH (pH value in between 7 and 10).



Fig. 15 Older version pH sensor calibration.

A) Electrode is placed into the solution of pH 7. B) Reading of the measured value.

4.4 AIR PUMP WITH BUBBLE INTERRUPTION VALVE

Air pump for culture bubble stirring and supply of air levels of CO₂. Valve interrupts bubbling during measurements, it is required for precise readings of OD, Ft and QY. Bubble interruption valve can be purchased also without air pump if required.

4.5 GAS SUPPLY

The gas supply to the photobioreactor consists of four main parts – pressurized gas source, bubble humidifier, the bubble interruption control valve, and gas dispenser tube (Fig. 17). All parts are connected with flexible silicone tubing.

The following instructions describe the proper installation of the gas supply for the photobioreactor:

- Connect gas source (**Note:** this can be pressurized gas from air pump or pressurized mixed air from other sources) with the bubble interruption valve via the silicone tubing.
- Prepare the bubble humidifier bottle: Components needed for bottle assembly are shown in Fig. 16A. Plastic lid with the ports insert into the screw cap. One end of the silicone tubings has FTLL Luer Lock (n°3 in Tab. 4) and Lock Ring Plug (n°4 in Tab. 4), the second has MTLL Luer Lock (n°1 in Tab. 4), as shown in Fig. 16B. Other silicone tubing of about 15-20 cm is connected to the other side of the plastic sleeve (Fig. 16B). Fill the bottle up to 1 liter with distilled water, insert the sealing ring into the screw cap and close loosely the bottle with the assembled lid and cover by aluminium foil. The ends of all the tubings should be covered with aluminium foil and the assembled aeration bottle should be autoclaved (Fig. 16C).
- After autoclaving, connect the bubble humidifier bottle as described in the following steps. Remove the Lock ring plug from the silicone tubing and connect the MTLL Luer Lock with FTLL Luer Lock placed in the main gas dispenser tubing. Prepare silicone tubing of approximately 30 – 35 cm length and connect it with bubble interruption valve as shown in Fig. 17. Connect 20 µm air filter* with the MTLL Luer Lock end of the silicone tubing from the humidifier bottle and via other FTLL Luer Lock connect with the silicone tubing coming from the bubble interruption valve.



***Note:** Air filter is not part of the components provided with PBR FMT 150.

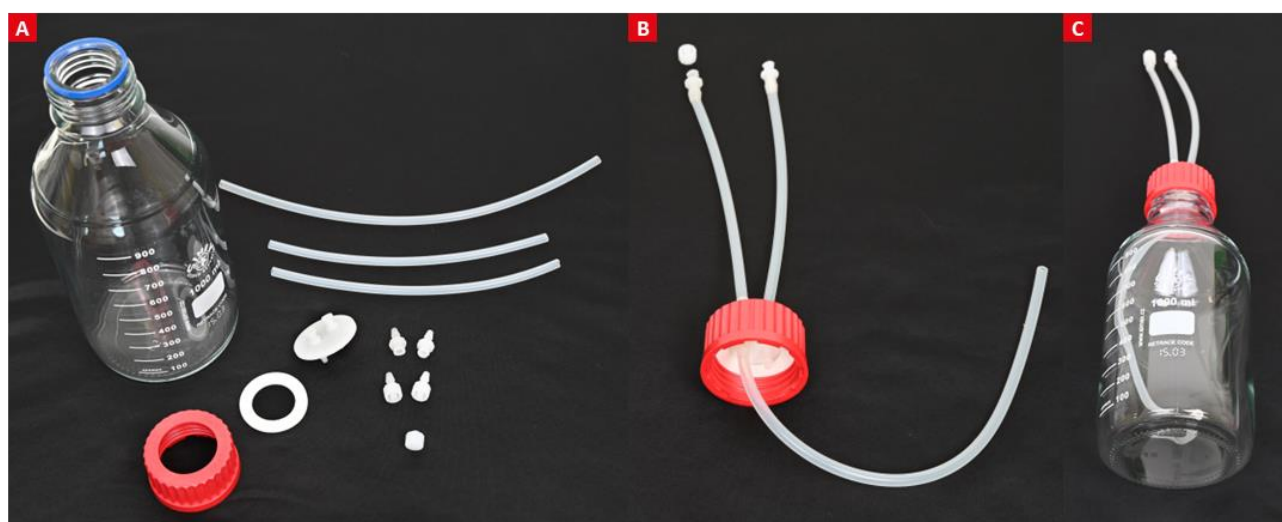


Fig. 16 Assembly of the bubble humidifier bottle.

A) Components needed for the assembly of the bottle. B) Assembled lid. C) Assembled bubble humidifier bottle.

- Connect the bubble interruption valve cable with the AUX2 connector on the back of the FMT 150.
- Switch on the air pump or other pressurized gas source.



Make sure that the waste fluid outlet tubing from the PBR is placed inside of the waste bottle. The gas from the PBR escapes via this tubing.

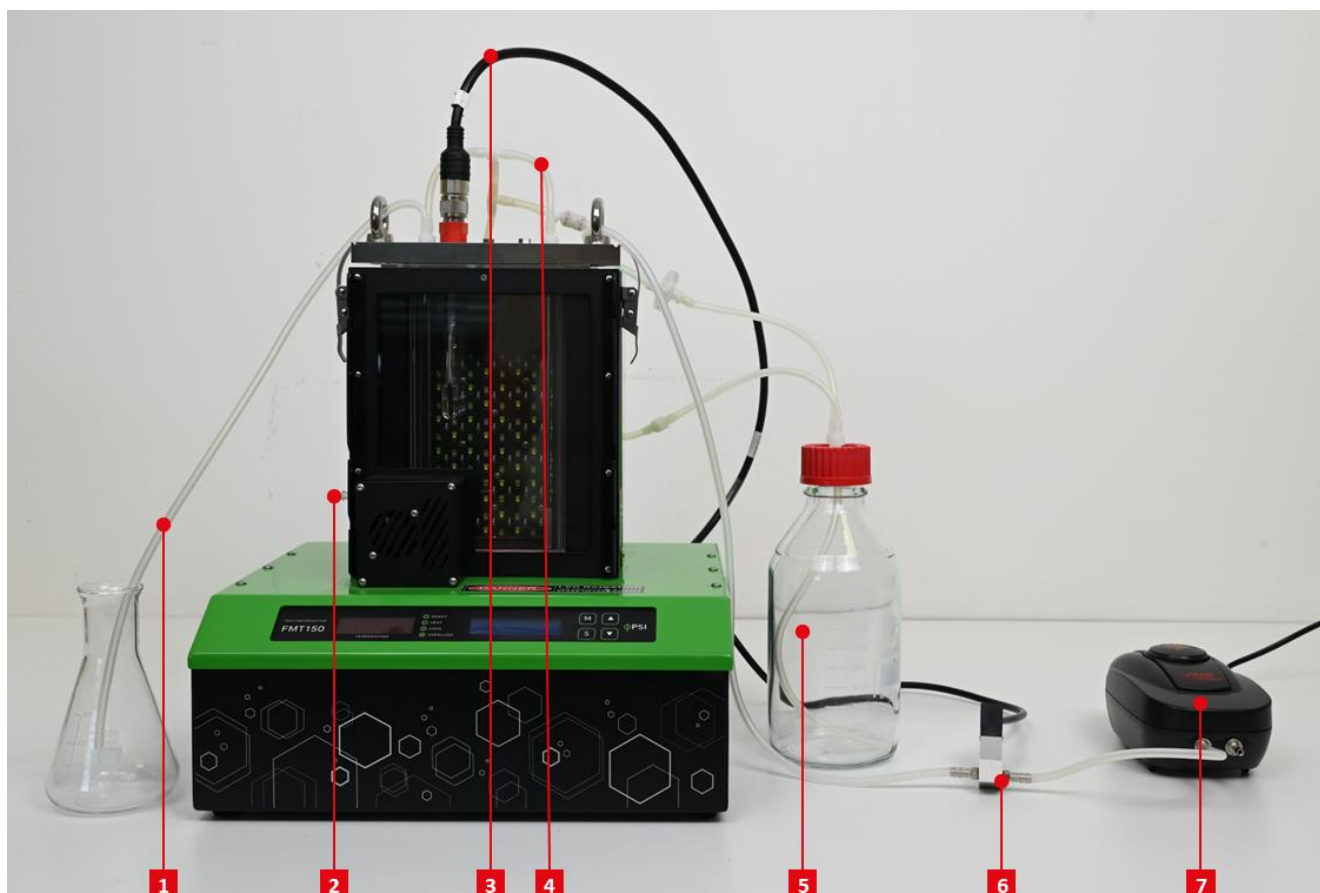


Fig. 17 FMT 150 set-up with air pump supplying the gas.

1) Excessive fluid outlet. 2) Air-blow unit. 3) Optical sensor. 4) Gas dispenser tube. 5) Bubble humidifier. 6) Bubble interruption valve. 7) Air pump.

4.6 PBR SOFTWARE

The Photobioreactor can be connected with an external PC that runs PBR software (Fig. 18). The PBR software can define, control, visualize and analyze experimental data and settings (overriding the photobioreactor controller) like

- duration of the experiment
- set up of user-defined protocols
- sensors data recording in real time
- regulation of temperature dynamics, LED irradiance, stirring, pumps, gas mixer, ...
- data export in various formats (Excel, CSV, XML)
- data visualization in graphs
- remote control via internet

The PBR software is necessary for recording of measured parameters from both the photobioreactor and the auxiliary sensors. If the PBR computer is connected to the internet, the data display, as well as regulation of the growth conditions can be managed remotely from anywhere.

The software operates on Linux operating system and allows. USB cable for PC and PBR FMT 150 communication is supplied with the system.

See the PBR Software manual for detailed description of software capabilities.



Fig. 18 Remote Control System for PBR FMT 150.

5 OPTIONAL ACCESSORIES/COMPONENTS

The functions of the PBR FMT 150 may be enhanced by wide range of optional components. Installation and operation of the optional accessories that can be provided together with the PBR FMT 150 device are described in next chapters.

5.1 O₂ MODULE



Fig. 19 O₂ module.

The O₂ module is designed for continuous monitoring of dissolved O₂ concentration in the culture medium. The module consists of electronic unit embedded in Photobioreactor FMT 150 Control Unit, sensor probe and sensor communication cable (Fig. 19). O₂ sensor InPro6800/12/120 from METTLER TOLEDO (www.mt.com) with integrated temperature probe is used for oxygen measurement. Operation of the InPro6800/12/120 sensor is based on polarographic measurement. For more information, please refer to manual provided by electrode manufacturer.



O₂ electrode is made of high-quality stainless steel, grade 316, which is autoclavable. Yet, we recommend to keep autoclaving to a reasonable minimum. Be aware that, although the O₂ electrode is made of high-quality stainless steel, a very aggressive growth medium can cause its corrosion. Consult your specific conditions with the electrode manufacturer.

5.1.1 INSTALLATION

Follow these instructions to install the O₂ sensor:

- Insert the O₂ electrode into the connector on the right side of the vessel lid and secure it tightly (Fig. 20A,B).



The placement of the O₂ sensor on the right side of the vessel is recommended as it needs to be close to the magnetic stirrer to ensure homogeneous mixing of the media and prevent localized depletion of O₂ near the electrode.

- Attach the cable labeled "O₂" to the electrode (Fig. 20C)
- Attach this cable to the connector at the back panel of the Photobioreactor. See the red arrow in Fig. 20D.

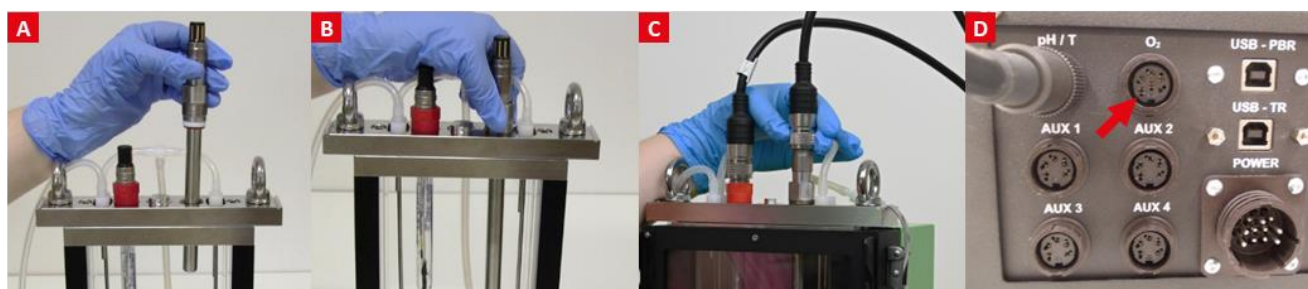


Fig. 20 Installation of the O₂ sensor.

A) Positioning the electrode. B) Securing of the electrode. C) Attaching the cable to the positioned O₂ electrode. D) Attaching the cable to the rear side of the PBR FMT 150.

- When connected to the PBR FMT 150 control unit, the sensor is automatically recognized. The function of the O₂ sensor can be controlled manually by the front panel of the control unit or by PBR software. For manual control please refer to chapter 7.1 on page 49 for more detailed explanation.
- Before first use of the electrode, we recommend to read the manual provided by the electrode manufacturer (www.mt.com).

5.1.2 CALIBRATION

The calibration of the dissolved O₂ probe can be performed with assistance of PBR software (for more details see the PBR Software manual).



It is very important to calibrate the O₂ electrode at the temperature that will be used during experiment. The output of the O₂ electrode is not temperature compensated and it is sensitive to temperature. Follow the instructions provided by electrode manufacturer and description in the PBR Software manual to perform the calibration.

5.2 DIGITAL CO₂ MODULE



Fig. 21 Digital CO₂ Module.

The new digital CO₂ module introduces potentiometric digital CO₂ sensor InPro5000i/12/120 from Mettler Toledo. Contrary to the analog sensor's version, the new sensor processes the electrode's signal differently which allows to use Intelligent Sensor Management (ISM) technology that provides sensor calibration and maintenance via iSense software from Mettler Toledo. For more details about ISM, please see www.mt.com.

The digital CO₂ module modifies and converts the signal from sensor (given in mbar) so that it could be readout by Photobioreactor unit and after that visualized in PBR Control Software as μmol of dissolved CO₂ per liter. The module ensures full compatibility of the new digital CO₂ sensor with all Photobioreactor's FMT 150 versions.

The CO₂ module contains new digital CO₂ sensor, Photobioreactor convertor unit for connection with Photobioreactor FMT 150, sensor's communication cable and USB convertor (Fig. 21).



The calibration and setting of the digital CO₂ sensor are different compared to the analog sensor in order to use full potential of the digital sensor and to ensure its compatibility with all PBR FMT 150 versions. The calibration of the CO₂ sensor needs to be carried out through the iSense software provided by Mettler Toledo. After that, the signal from digital CO₂ sensor is modified and converted by Photobioreactor Convertor to $\mu\text{mol/l}$ and displayed in the PBR software. To get correct values, it is crucial to adjust the CO₂ calibration constants in the PBR software properly. Please read carefully following chapters concerning CO₂ sensor calibration and setting.

5.2.1 INSTALLATION

Follow these instructions to install and operate the CO₂ sensor:

- Before the first use of the sensor, we recommend reading the manual provided by the sensor manufacturer (www.mt.com).
- Assemble the sensor according to the manual provided by the sensor manufacturer. Individual steps of the assembly are schematically shown in Fig. 22.

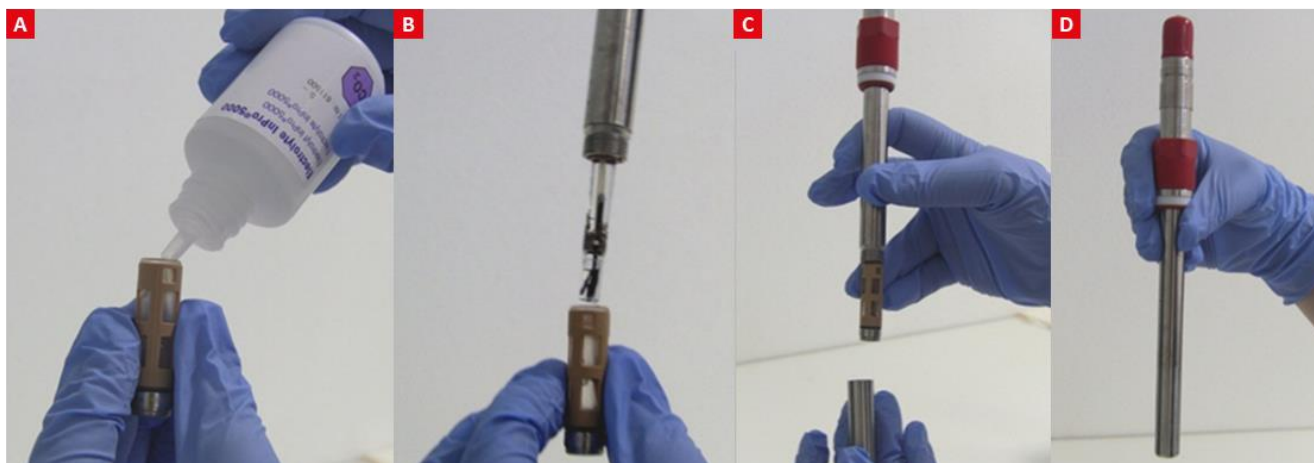


Fig. 22 Assembly of the CO₂ electrode.

- Insert the CO₂ sensor into the vessel's lid connector and secure it tightly (Fig. 23A).
- Attach the sensors' communication cable to the sensor and plug the other end into one of the three Photobioreactor convertor's connectors. The connectors are identical. (Fig. 23B-C).
- Connect the Photobioreactor convertor and PBR FMT 150 using one of the "AUX 1 – AUX 4" connectors at the rear side of the Photobioreactor (Fig. 23D). If no AUX port is available, use the "AUX out" connector of the additional components such as peristaltic pump as indicated in Fig. 7 on page 16.

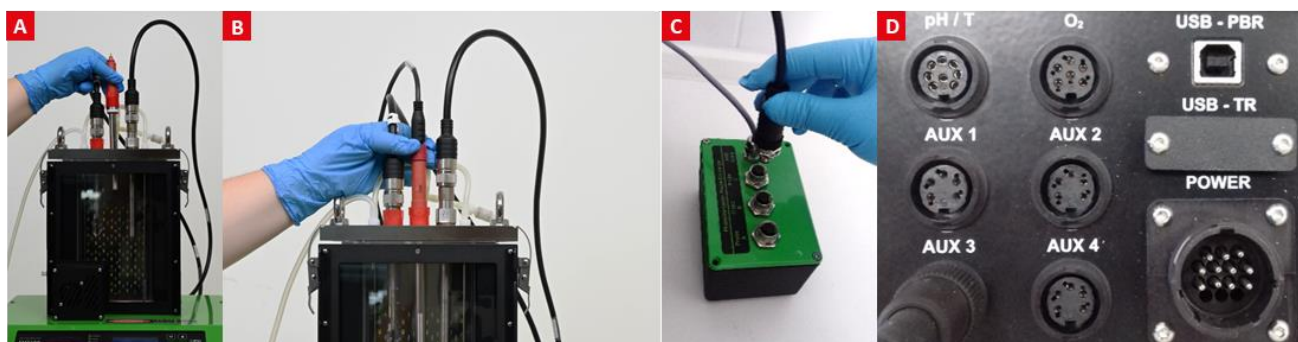


Fig. 23 Installation of the CO₂.

A) Positioning the sensor. B) Attaching of the electronic module to the sensor. C) Attaching of the communication cable to the PBR's convertor. D) Attaching of the communication cable to the "AUX1, AUX3 or AUX4" connector at the rear side of the PBR.

5.2.2 CO₂ SENSOR CALIBRATION WITH ISENSE SOFTWARE

To display CO₂ values as CO₂ concentration, it is important to perform a sensor calibration prior its use. The calibration of the CO₂ sensor is performed with an assistance of iSense Light software from Mettler Toledo.

The software operates on Windows operating system. Download and install the iSense Light from https://www.mt.com/de/en/home/library/software-downloads/process-analytics/iSense_light.html. To open the software, use ADMIN and 1989 for login and password, respectively.

The sensor calibration involves two parts:

1. pH electrode calibration
2. CO₂ process calibration

For more details, please check carefully the instruction manual that was delivered with the CO₂ sensor and also following tutorial: <https://www.youtube.com/watch?v=vniXvaORSLg>.

Remarks related to the CO₂ sensor calibration:

- In case, the sensor hasn't been used for a while, remove the wetting cap, cap sleeve with membrane body and immerse the pH electrode into 3M KCl overnight.
- Prior the calibration of the pH electrode, insert the pH electrode into buffer 7 for 15 minutes.
- The CO₂ process calibration can be performed in a gas phase as well – capture the reference (process) CO₂ value while flushing the empty cuvette with the appropriate CO₂ gas mixture.



In case the CO₂ process calibration is performed in the cuvette filled with medium (liquid), the galvanic isolation of the cuvette must be ensured as follows:

- take out the cuvette from the Photobioreactor and disconnect all other sensors placed in the cuvette (pH, O₂ sensor, etc.) from the rear side of the Photobioreactor,
- disconnect the computer with iSense software from the mains while performing calibration.

Please remember that improper galvanic isolation causes drift of CO₂ values which prevent the sensor to stabilize and perform correct calibration.

5.2.3 CO₂ SENSOR SETTING WITHIN PBR CONTROL SOFTWARE

Contrary to the analog sensors, the digital CO₂ sensor is calibrated through the iSense software and not via the PBR software. The digital CO₂ module modifies and converts the signal from sensor and so, the right adjustment of the PBR software CO₂ calibration is essential in order to ensure correct visualization of CO₂ concentration in µmol/l.

Adjust the CO₂ calibration within the PBR software:

- Insertion of following calibration constants: $a = -0.00028$, $b = 73000$. The calibration constants are stated on the Photobioreactor convertor and are identical for all CO₂ sensors.

The calibration constants must be adjusted for each CO₂ sensor (i.e., related Photobioreactor) separately.

For more details about constants insertion or calibration file import, refer to the Bioreactor Software Manual, chapter Calibrations: <http://photo-bio-reactors.com/products/software/#download>.

Please note, that CO₂ values displayed in PBR Control Software as “raw CO₂ data” are just auxiliary and recalculated values from the Photobioreactor Convertor and no real electrode’s raw data (mV).

5.3 MAGNETIC STIRRER

The magnetic stirrer module is designed for homogeneous mixing of the culture inside the cultivation vessel. The stirrer is essential when the agitation by air or gas bubbles cannot be used, e.g. when the photosynthetic oxygen evolution or respiratory oxygen uptake are measured or when growing the culture anaerobically without gas supply. It can be also used to reduce cell sedimentation and clumping in addition to agitation by gas bubbling. The magnetic stirrer is highly recommended when using the O₂ probe and CO₂ probe – very good stirring is essential for accurate measurements of these probes.

The magnetic stirrer (Fig. 24) rotates – 35 mm long (Ø 6 mm) teflon-coated magnetic bar in a vertical plane of the front glass panel inside the Photobioreactor. The speed of rotation is adjustable from 60 to 600 rpm (10 – 100 %) by the front panel of the control unit (Setting > PWM mode) or by the PBR software. The current version of the magnetic stirrer has own external control unit as shown in Fig. 24.

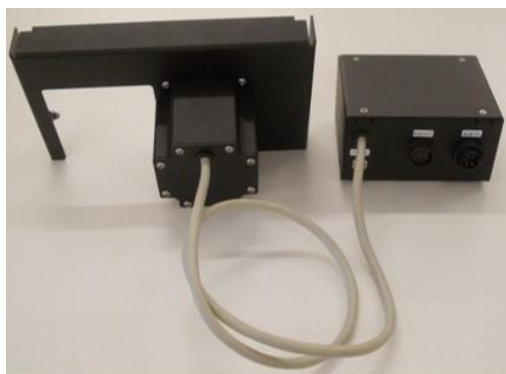


Fig. 24 Magnetic stirrer.

The current version of magnetic stirrer implements a stepper motor powered by direct current (12 VDC/2 A) in contrast to the older versions that comprised of a brushed electric motor driven by an alternating current. The main advantages of this technology represent linear response of stirrer to applied voltage, better lifetime of motor, improved control and accuracy that is not influenced by density or viscosity of mixed solution, lower susceptibility to failure, increased rotation speed and range, improved guarantee of the rotation speed, etc. The motor is controlled by an additional external control unit which allows precise adjustment of rotation speed either via front panel of the Photobioreactor or the PBR software. The speed of rotation can reach up to 600 rpm and is fully and continuously adjustable in range of 60 – 600 rpm which corresponds to 10 – 100 % setting of PWM_mode. Optimal gradual acceleration and deceleration of the stirrer is preset by manufacturer and this parameter can't be changed by user. Moreover, PBR control software allows to set different stirring modes: constant, linear, sinusoid or through scripts.

The older versions had slow-speed of rotation (labelled as 245) or high-speed of rotation (labelled as 770). The relation between rpm and PWM value (%) of rotation speed please refer to Fig. 25.

The front panel of the control unit houses connectors for all connecting cables (Fig. 29B). A metal button and USB port intended for services purposes are located on the rear side of the power supply (Fig. 29D). **DO NOT USE THE SERVICE BUTTON WITHOUT PSI MANUFACTURER! LET THE SERVICE BUTTON IN HORIZONTAL POSITION** (Fig. 29D).

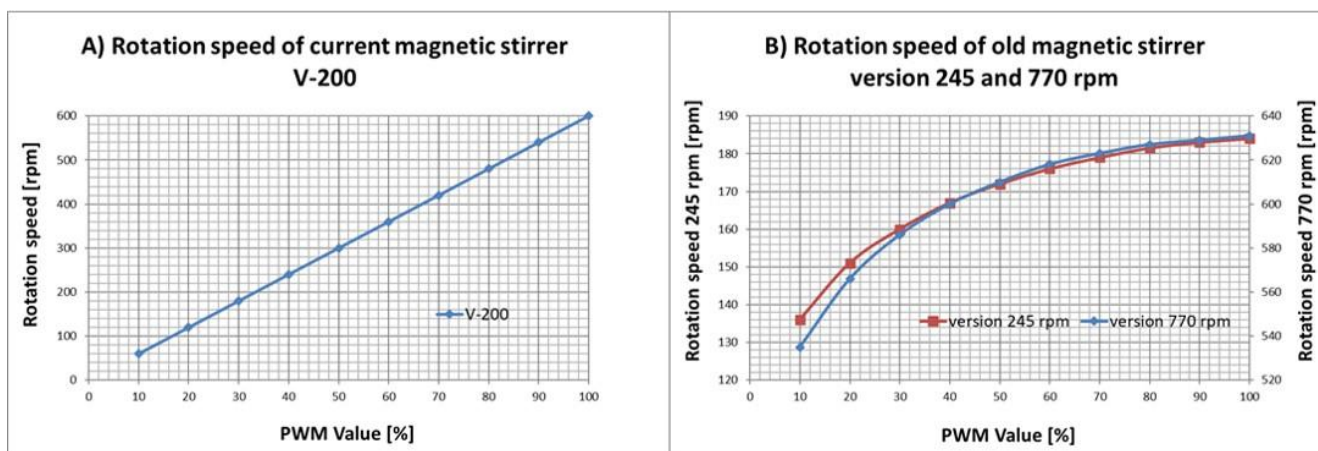


Fig. 25 Relation between rotation speed in rpm and PWM value in % adjusted by the PBR.

A) Refers to the current magnetic stirrer (600 rpm) version for PBR FMT 150. B) Refers to slow-speed and high-speed magnetic stirrer for older version PBR FMT 150.



Components for the magnetic stirrer: power source, communication cable (AUX cable), magnetic bars, service keys (Fig. 26).

Fig. 26 Components for the magnetic stirrer.

5.3.1 INSTALLATION

Follow the instructions below to install the magnetic stirrer:

- Magnetic stirrer has four screws positioned on each side of the inner holder as shown with red arrows in Fig. 27.
- Position the stirrer with the inner side towards the PBR front window by positioning the screws on the inner side of the stirrer as shown in Fig. 28.
- Connect the AUX cable to AUX1 connector on the back of the Photobioreactor (Fig. 29A) and the opposite end of the cable plug into the AUX IN on front side of the power supply (Fig. 29B).
- In case there is no sufficient size of AUX connectors on the rear panel of the Photobioreactor for an additional device (see Chapter 3.4) it is possible to use AUX OUT connector on the front side of magnetic stirrer control unit for this purpose.
- **Important note:** Please note that the communication connection scheme with the PBR FMT 150 varies depending on the complete set-up of the system. Please refer to page 16 Fig. 7 for schematic representation of different connection set ups based on the system composition.
- Connect control unit via power supply to the mains electricity.
- Insert the stirring bar inside the Photobioreactor cultivation vessel during cuvette assembly as described on page 20.
- The function of the stirrer can be controlled manually by the front panel of the control unit and remotely via PBR control software for PBR FMT 150.

- For manual operation via front panel please refer to chapter 7.1 on page 49 for more details. Briefly go to menu Setting > PWM_Mode. Here the stirrer can be turned ON/OFF and its speed can be adjusted in percentage of total power (10 % low power, 100 % high power) as shown in Fig. 29C.
- For setting via PBR control software refer to Photobioreactor software manual.

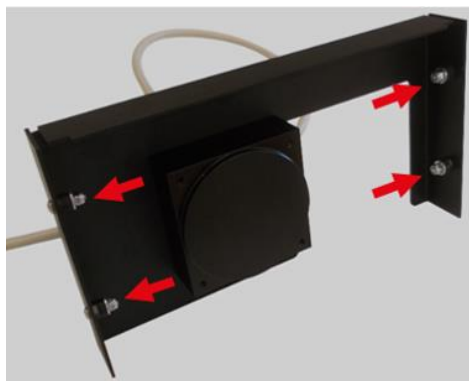


Fig. 27 Screws for fixing the stirrer to the front side of the PBR main body.



Fig. 28 Magnetic stirrer is fastened in the correct position to the front part of the PBR.



Fig. 29 Attaching of the AUX cable (A, B) and manual control (C) of magnetic stirrer.

A), B) Attaching of the communication cable to the “AUX1” and “AUX IN”. C) Manual Stirrer control via the PWM_Mode on the front panel of PBR. D) Horizontal position of the service button.



Magnetic stirrer cannot be used simultaneously with an external light panel as they both fit on the outside of the vessel.

5.4 PWM PUMP

PWM pump (Fig. 30) can be used for pumping liquid or gas into the cultivation vessel. It can be regulated within a range of 10 – 100 % of total output. The pump has diverse uses:

1. Controlling air bubbling in the cultivation vessel.
2. Single gas input into the vessel.
3. When connected to the vessel inlet and outlet (closed flow mode), it can be used for suspension mixing (bubbling) in anaerobic conditions.



Please note that PWM pump cannot be used simultaneously with magnetic stirrer as both need to be connected to AUX1 on the rear side of the photobioreactor.



Fig. 30 PWM Pump.

5.4.1 INSTALLATION

Instructions below explain connection of the PWM Pump with the Photobioreactor FMT 150:

- The function of the PWM pump can be controlled manually by the front panel of the control unit and remotely via Remote Control software for PBR FMT 150. For manual operation via front panel please refer to appendix on page 49 for more explanation. Briefly go to menu Setting > PWM_Mode. Here the PWM pump can be turned ON/OFF and its performance can be adjusted in percentage of total power (10 % low power, 90 % high power).
- PWM Pump when connected to the PBR has to be set for REMOTE MODE operation to be directly controlled and operated via Remote Control software for PBR FMT 150. This pump can also be used in a manual mode as a stand-alone instrument.



When connected to the PBR and used In REMOTE MODE PWM Pump can replace the function of the Bubble Interruption Valve.

- For REMOTE mode plug the grey connector cable to the PWM pump rear and connect it with the AUX1 connector of the PBR FMT 150. Set the speed control of the PWM Pump to **REMOTE MODE** position (Fig. 31B). PWM Pump is now controlled via PBR FMT 150 software.
- For the stand-alone MANUAL mode operation connect the PWM Pump power supply with the PWM Pump and plug to AC outlet. The flow rate can be controlled manually with the speed control knob on the front panel.



If MANUAL mode of the PWM Pump is used for controlling air bubbling in the cultivation vessel, bubble interruption valve must be used to interrupt the bubbling during the measurements.

- Connect the short silicone tube to the **IN** port on the rear panel of the PWM Pump. (**Note:** This improves supply of homogeneous gas flow to the pump). Connect the silicone tubing between the **OUT** port on the PWM Pump rear panel with the humidifier bottle (Fig. 31C) or with the bubble interruption valve (Fig. 17) depending on the configuration used.



Fig. 31 PWM Pump control and connection.

A) PWM Pump components. B) Front panel with the speed control knob in REMOTE MODE position. C) Connection of the PWM Pump with the humidifier bottle.

5.5 GAS MIXING SYSTEM GMS 150

Gas Mixing System GMS 150 (Fig. 32) can produce precise mixtures of up to 4 different gases. The flows of the individual input gases are measured by thermal mass flow meters and adjusted by integrated mass flow controllers. The gas mixture is thoroughly homogenized, before leaving the device. The input and output gas connectors are of Prestolok type allowing fast and secure connection to a variety of tubes.

The gas mixer can have up to four channels (gases). The standard version of the system includes two channels:

- Channel 1 supplies Air-N₂ mixture or Air and has flow rate 40 – 2,000 ml/min
- Channel 2 supplies CO₂ and has flow rate in range 0.8 – 40 ml/min

Please note that when one GMS is used to supply gas to more than one photobioreactor, the use of one PWM pump per photobioreactor is required to supply portion of the gas from the gas mixing system to the bioreactor without affecting the gas flow among the bioreactors. The GMS 150 mass flow meters and controllers can operate gas flows ranging from ml/min to tens of l/min. Typically, the controllers of GMS 150 operate in the lowest range 0 – 8 ml/min and in the highest range 0 – 2,500 ml/min.



The user can define the required gas mixture either by setting the flows of the individual gases (e.g., 980 ml/min of N₂ and 20 ml/min of CO₂) or by setting the required relative composition of the gas mixture (2% CO₂) and the mixture gas flow (1,000 ml/min). The GMS 150 can be used as a stand-alone instrument with other applications or as an additional and optional component of the Photobioreactor FMT 150. The GMS 150 can be controlled also by PBR software. Detail description of the High-precision Gas Mixing system installation and operation can be found in the manual provided together with the Gas Mixing (GM) System and in the PBR Software Manual.

Fig. 32 GMS 150.

5.5.1 INSTALLATION

Follow the instructions below to connect the Gas Mixing System with the PBR FMT 150:

- Use Parker Prestolok tubing (Ø 6 mm) for gas inputs and gas output.
- Connect the GM System with the gas sources (n°1 in Fig. 33A) and set the desired composition of the gas via the front panel display of the GMS 150 or PBR software.
- Connect the output GM system tubing (n°2 in Fig. 33A) with the bubble interruption valve (n°3 in Fig. 33A). Bubble interruption valve is further connected to PBR FMT 150 as shown and described in Fig. 17.
- Insert a hydrophobic filter between the bubble interruption valve and humidifier. The filter is not part of the delivery. Use for example a syringe hydrophobic filter with PTFE membrane with pore size of 20 µm.
- Level of gas input tubing into the humidifier should be at least 15 cm higher than level of gas output tubing from the humidifier. See Fig. 33C. This configuration will prevent a flooding of the gas mixing system caused by water recoil when sparging is stopped.
- When the GM System is connected to the PBR FMT 150 the vessel lid assembly scheme (Fig. 33B) is same as for standard air installation as described on page 20.

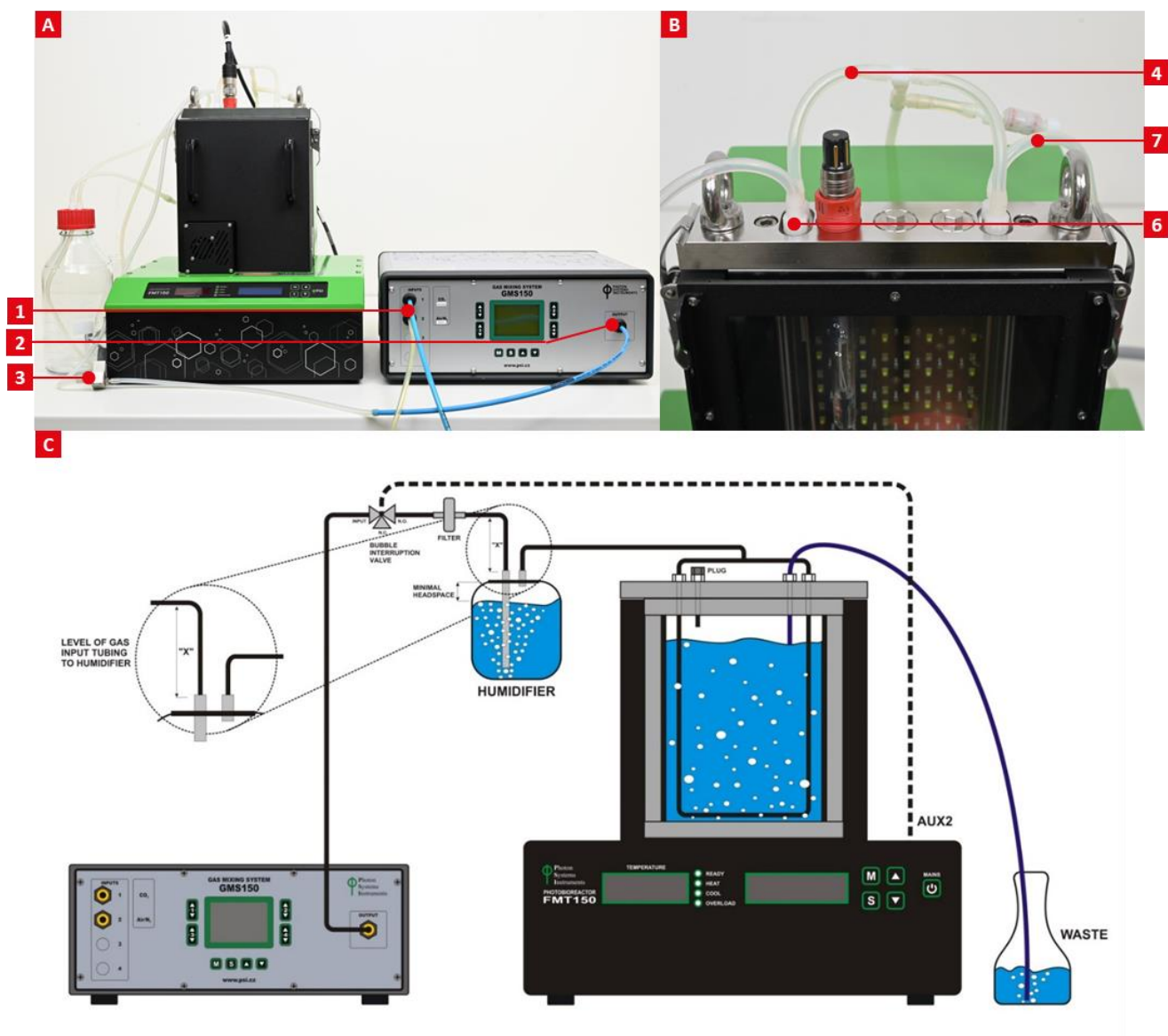


Fig. 33 GM System connection with the PBR FMT 150.

A) Mixed gas of given composition (1) is pumped from GM System via (2) to the PBR FMT 150 via air interruption valve (3). B) Vessel lid assembly. (4) Air distribution, (7) Medium outlet, (6) Sampling tube. C) Scheme for the connection of GM with PBR FMT 150.

- When more than one PBR FMT 150 units are connected to the same GM system the set-up of such connection scheme is shown in Fig. 34. For connecting more PBR FMT 150 units to one GMS 150 system the customer needs to purchase one PWM pump for each PBR FMT 150 unit.

Output flow tubing from the GMS 150 should be connected with the individual PWM pumps such that the final sum of the GMS 150 flow rate (schematically described in Fig. 34 as V_{GMS}) is bigger than the sum of each PWM pump flow rate.



That the end of the output flow tubing from the GMS 150 to which the individual PWM pumps are connected must be open to allow release of residual air from the tubing.

For installation of PWM pumps and their connection to PBR FMT 150 please refer to chapter 5.4 on page 34.

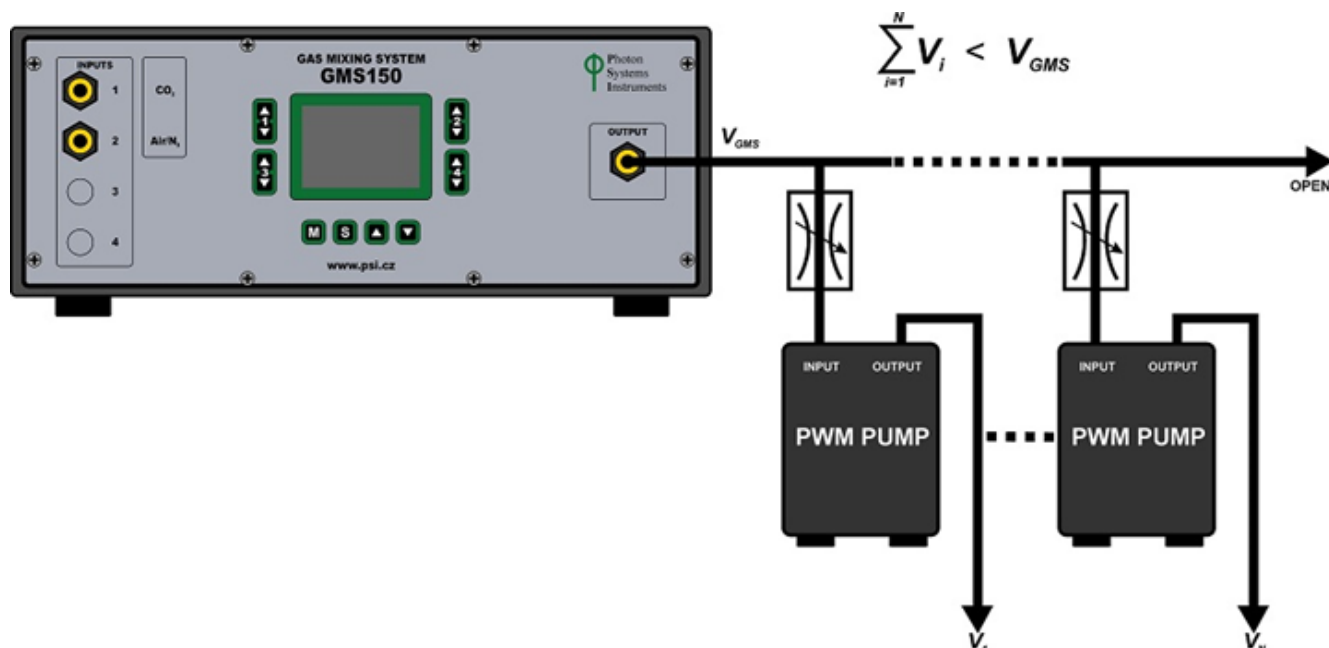


Fig. 34 Scheme for connecting more PBR FMT 150 units to one GM System.

V_i refers to air flow to one PBR unit. V_{GMS} refers to total air flow output of GM unit.

5.6 PERISTALTIC PUMP PP600

Peristaltic pump PP600 (Fig. 35) can be used in chemostat, turbidostat or standalone cultivation mode. Please note that PBR software is required to use the pump in turbidostat or chemostat mode.



The operation of the peristaltic pump cannot be controlled by the front panel of the PBR FMT 150 control unit. Without the PBR software, the operation of peristaltic pump is controlled solely by the Peristaltic pump Control display.

Important note: It is essential to define if the pump is serving for turbidostat or chemostat module or if it is working in standalone mode. It is done in the Peristaltic Pump control display – go to **Menu > Setting > Pump-ID [x]** and set the required mode as described below:

- [0] should be set for turbidostat mode
- [1] should be set for chemostat mode – Acid
- [2] should be set for chemostat mode – Base
- [3-7] should be set for standalone mode



The pumps connected to the FMT 150 must have unique IDs, otherwise the behavior of pumps is unpredictable.

Turbidostat mode – the Photobioreactor optical sensing unit monitors the optical density (OD680, OD720) of the culture. The Peristaltic Pump adds fresh medium to maintain configured OD levels according to protocol defined in PBR software.

Chemostat mode – the pH value of the cultivation media can be continuously adjusted as either acid or base is added to the cultivation vessel to keep the pH level at given value according to protocol defined in PBR software.

Standalone mode – controlled manually via the peristaltic pump control display or by PBR software. For manual control please refer to the Peristaltic Pump operation manual.



Fig. 35 Peristaltic pump PP600.

The pump allows variable flow-rate from 0.2 to 50 ml/min and this flow rate is set manually on the pump control display or via PBR software for each pump.

The Peristaltic Pump consists of two main parts – the Peristaltic Pump PP600 and the small stabilized power supply. Detail description of the pump can be found in the manual provided together with the peristaltic pump.

5.6.1 INSTALLATION

Follow the instructions below to install and operate the peristaltic pump:

- First install the tubing connection with the PBR FMT 150.
- Attach provided short tube with Male Luer Lock Fittings (n°1 in Tab. 4) to the Peristaltic Pump PP600. Insert one end of the tube in the holder and wind the tube as shown in the figure below (Fig. 36A,B). Insert the other end of the tube into the holder (Fig. 36B). Ensure that the end of the tubing is pushed all the way to the end of the Luer Lock Fitting. If this is not done, small air leak may occur resulting in the pump not working properly.

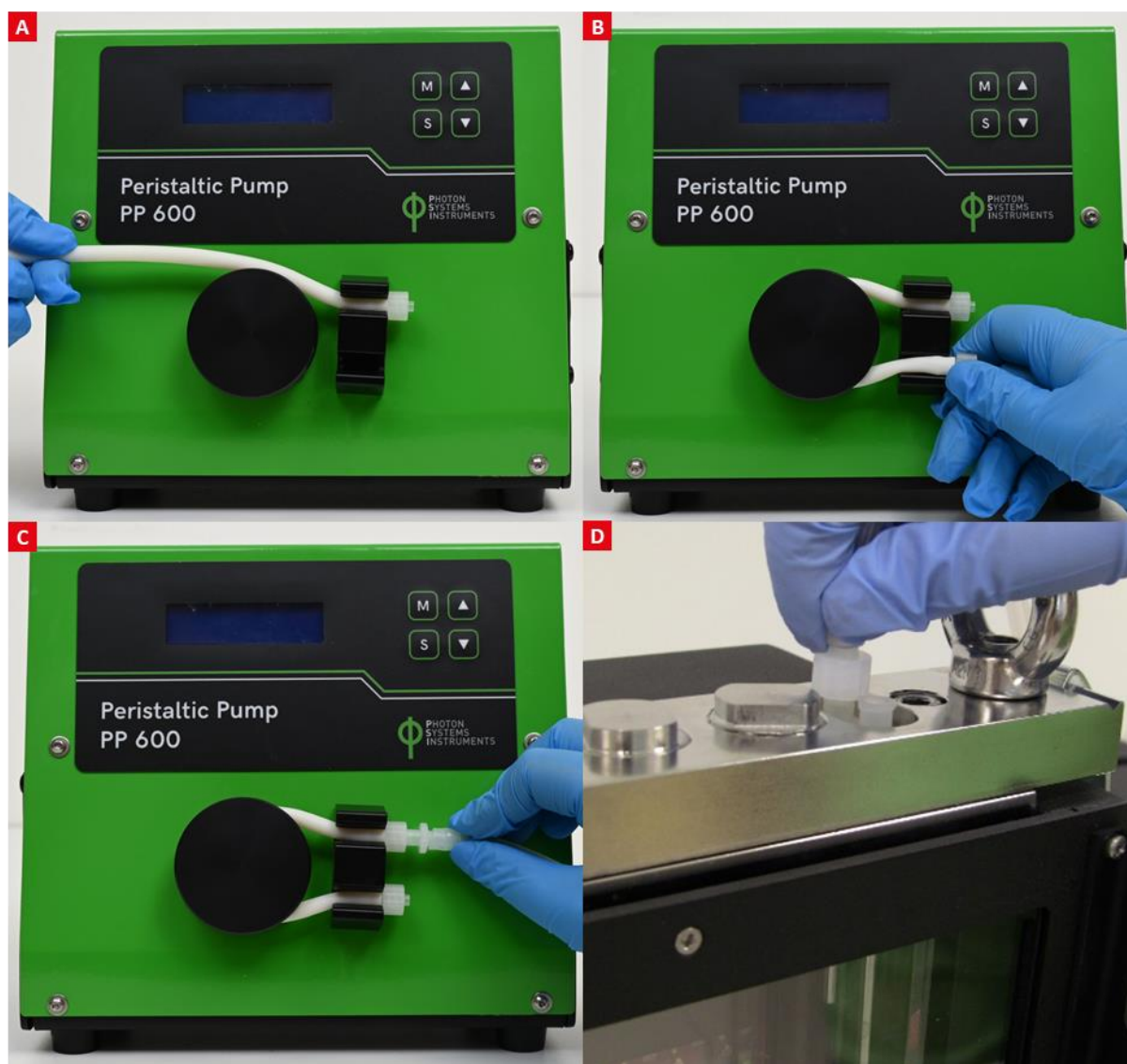


Fig. 36 Assembly of the peristaltic pump.

A, B) Short tube is attached around the rotor wheel to the peristaltic pump. C) Adapter is attached to the silicone tubing and connected with tubing of the peristaltic pump. D) Tubing from the peristaltic pump is connected with the cultivation vessel.

- Attach provided female luer connector to the silicone tube and connect it to the peristaltic pump as shown in Fig. 36C. Again, ensuring that the tubing is pushed all the way to the end of the luer lock connector.
- Connect the free end of the silicone tube via Male Luer Lock Fitting with the lid of the cultivation vessel (Fig. 36D). The position for connection on the vessel lid corresponds to the position of outlet n°6 in Fig. 10C.
- Attach a new piece of tubing to another female luer connector and attach it to the Peristaltic Pump as shown in Fig. 37A.
- Place the other end of this tubing in the suspension or medium (Fig. 37B) depending on the application of the pump.

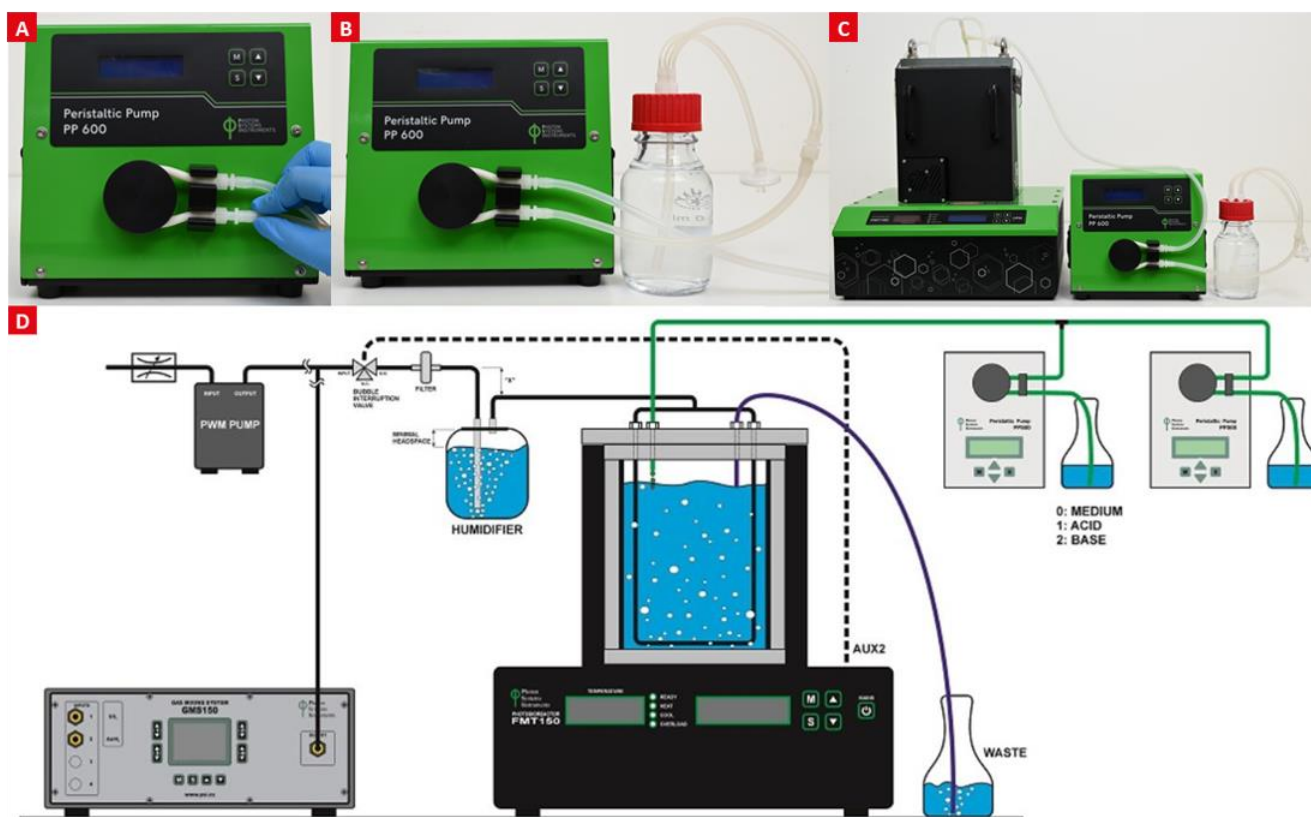


Fig. 37 Final assembly of the peristaltic pump.

A) Second luer connector is attached. B) Connection of the silicone tubing with the medium for cultivation. C) Fully installed peristaltic pump tubing. D) Schematic representation of PBR FMT 150 unit connected to peristaltic pumps in chemostat and turbidostat mode and to GMS 150.

- Connect the silicone tubing from the peristaltic pump to the vessel lid. Peristaltic pump tubing is attached to the outlet for the sampling tube (n°6 in Fig. 10A,C). Please refer to Fig. 37D for schematic representation of the PBR FMT 150 set-up when peristaltic pump module and GM module is included.
- Install the wiring connections for the peristaltic pump as shown in Fig. 38.
- Connect the Photobioreactor and the Peristaltic Pump using provided communication cable.



Please note that the communication connection scheme with the PBR FMT 150 varies depending on the complete set-up of the system. Please refer to page 16 Fig. 7 for schematic representation of different connection set ups based on the system composition.

- Connect the Peristaltic Pump via the power supply cord into the **POWER** connector of the Peristaltic Pump (Fig. 38A).
- Plug one end of the communication cable into the **AUX IN** connector of the Peristaltic Pump (Fig. 38C).
- Plug the other end of the cable into the **AUX 1** or other available AUX connectors at the rear of the Photobioreactor (Fig. 38B). Please refer to page 16 for further information.
- See Fig. 37D for complete setup of the Peristaltic Pump.

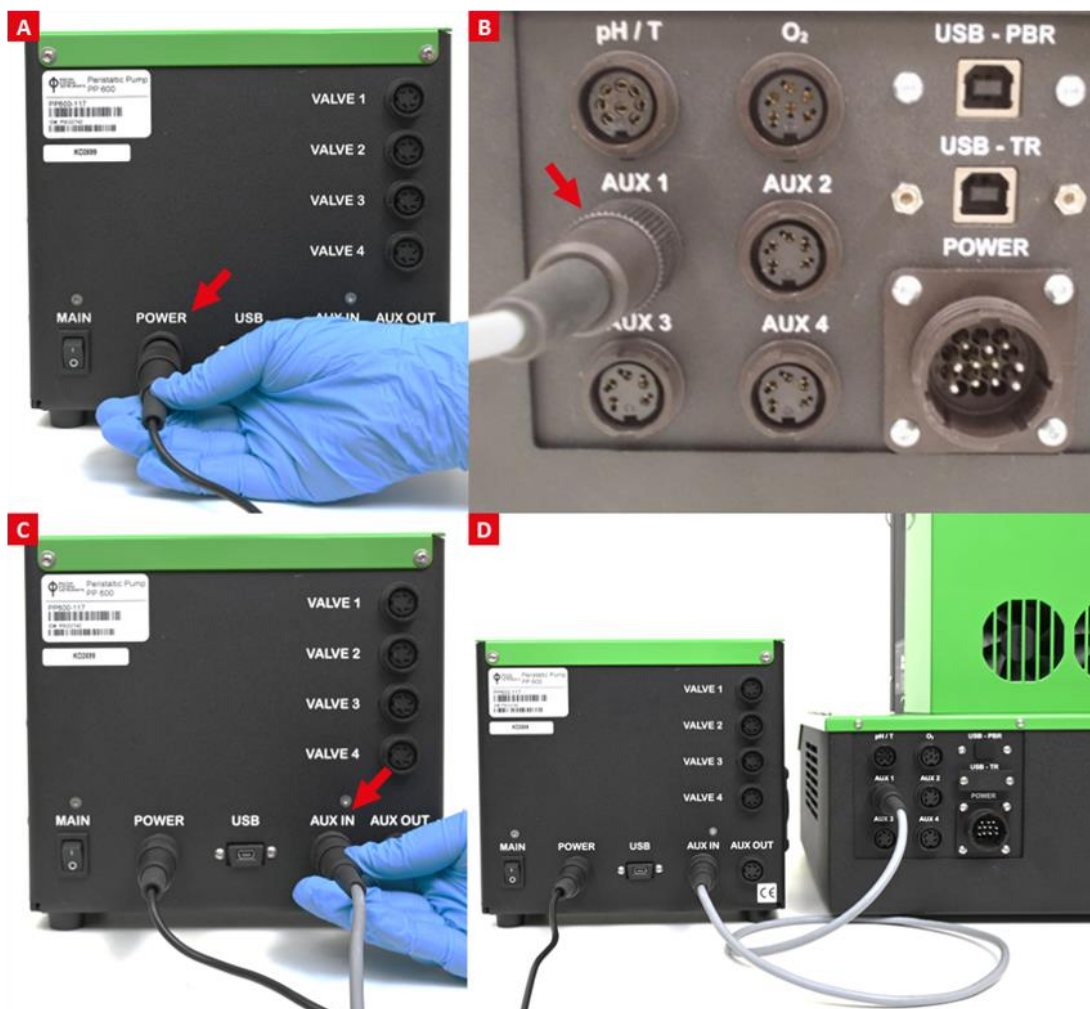


Fig. 38 Connection of peristaltic pump with PBR FMT 150.

5.7 pH STAT MODULE

The module is intended for pH-stat cultivation which is driven by automatically controlled CO₂ sparging. The module includes Peristaltic Pump PP600 and an assembly of Gas valve and Flow control valve (pH stat kit - Fig. 39). Supporting control software and additional tubing is needed (Parker polyflex presto TPU 6x1 tubing is delivered with pH stat module and silicone tubing Ø 6/3 mm is delivered in spare kit with the Photobioreactor FMT 150). The CO₂ and Air sources for sparging of the biomass are not included.

The Gas valve together with PP600 is intended for CO₂ flow regulation (ON/OFF) depending on target and actual pH value of the suspension. Once a higher pH than the set value is detected then the PP600 opens the Gas valve for CO₂ sparging. The Flow control valve allows manually to lower or increase the added CO₂ flow. This allows to control a level of pH drop after the CO₂ addition to the suspension. The Flow control valve has to be open partially in the beginning of the experiment.



Fig. 39 pH stat kit.

5.7.1 INSTALLATION

Follow the instructions below to install and operate the pH stat module:

1. Connect the power supply cord of PP600 to the **POWER** port (Fig. 40A).
2. Connect the PP600 with the PBR: plug one end of the communication cable (AUX cable) into the **AUX IN** port of the PP600 (Fig. 40A) and the other end into the **AUX 1** port on the rear side of the Photobioreactor (Fig. 40B).
3. Turn on the Main switch.
4. Connect the pH stat kit with the PP600: plug the cable to the **VALVE 1** port on the rear side of the PP600 (Fig. 40D).

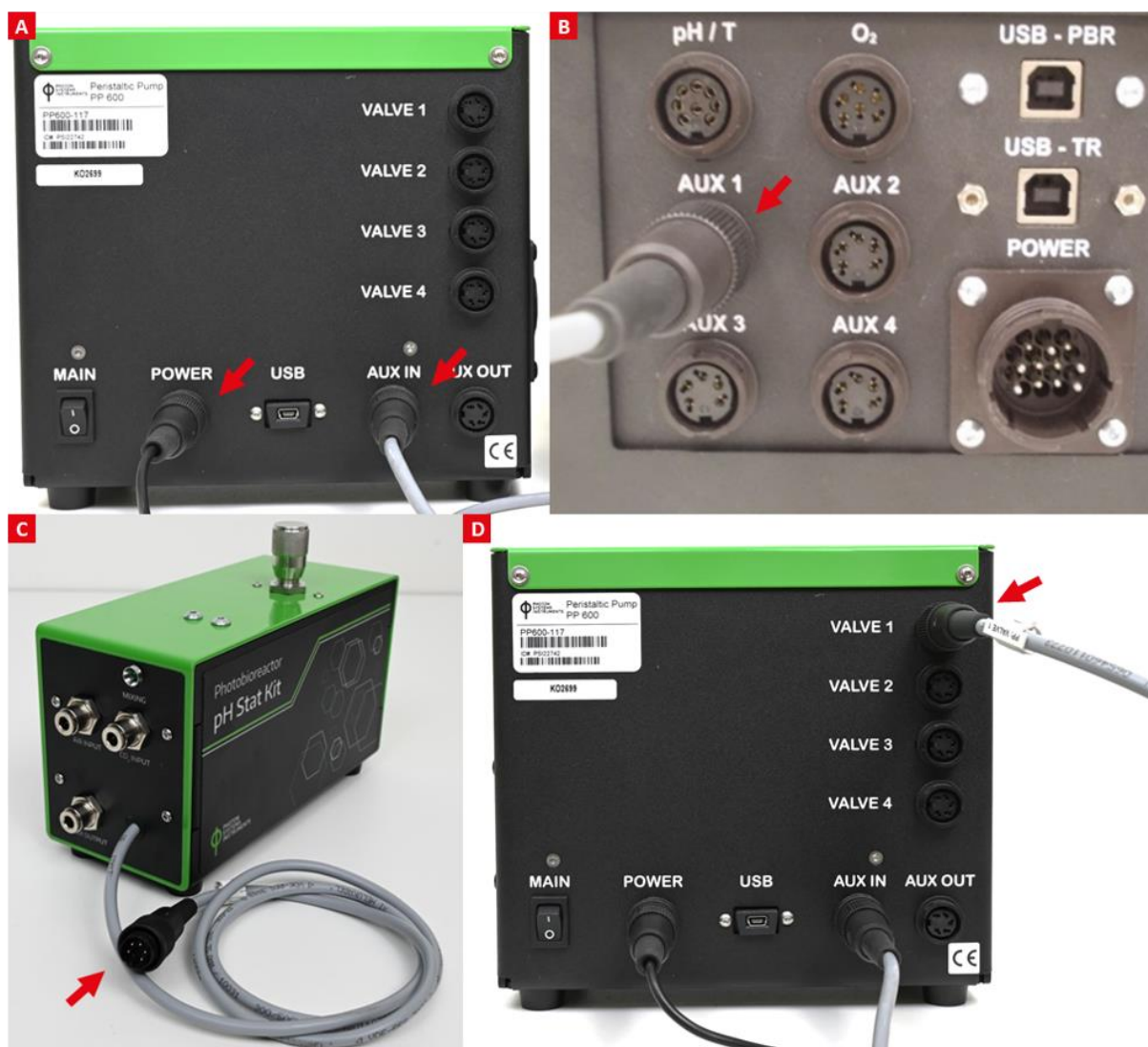


Fig. 40 Connection of peristaltic pump and pH stat kit with PBR FMT 150.

5. Connect the Parker tubing for CO₂ and Air delivery as shown on Fig. 41. **Use the input gas pressure around 1 bar.** In case a pressurized source of CO₂ or Air will be used it is necessary to lower the outcoming gas pressure via any pressure reducing valve to the appropriate level before connecting the gas source to the pH stat kit.

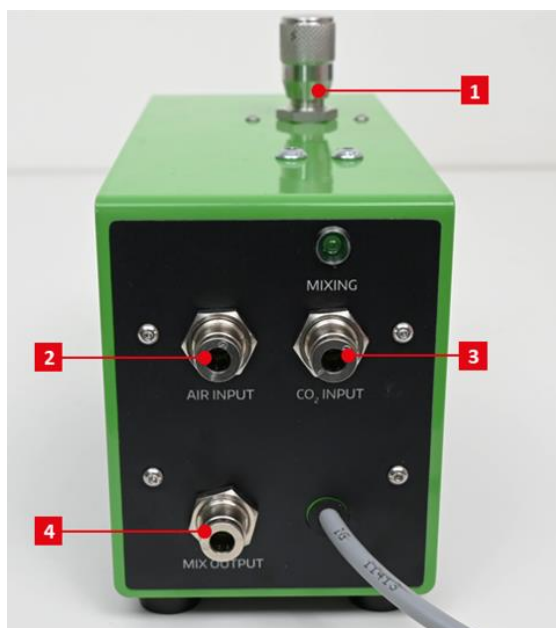


Fig. 41 Connection of Parker tubing to the pH stat kit.

1) Flow control valve (manual). 2) Air input. 3) CO₂ input. 4) Final mixture output.

6. Connect the output Parker tubing containing the final mixture of CO₂ and Air via the silicon tubing with the bubble interruption valve and humidifier as shown on Fig. 42.

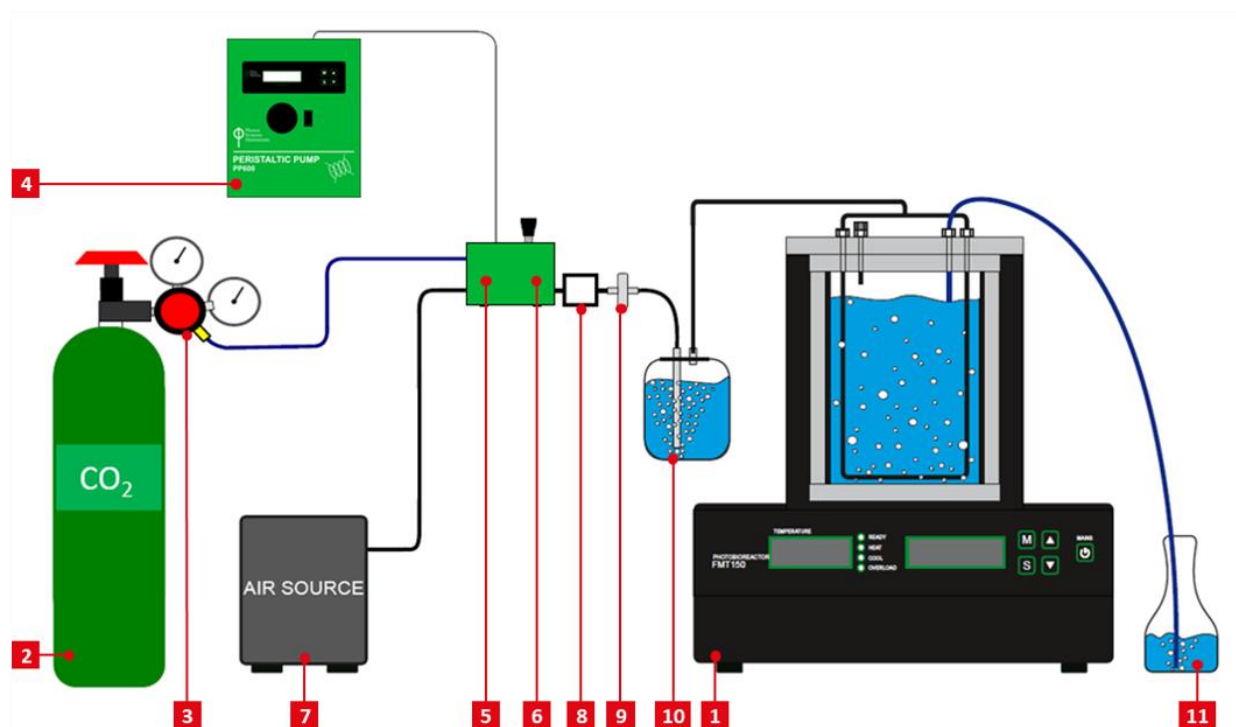


Fig. 42 Final assembly of the pH stat module.

B) Schematic representation of PBR FMT 150 unit connected to peristaltic pump in pH stat mode – 1) PBR FMT 150, 2) source of CO₂, 3) pressure reducing valve or regulator, 4) PP600, 5) opening and closing gas valve, 6) manual flow control valve, 7) source of air, 8) bubble interruption valve, 9) air filter, 10) humidifier, 11) waste bottle.



Don't connect CO₂ and Air tubing in other way! Wrong connection can cause a damage because of over pressurizing or flooding the system.

7. The setting of PP600: It is necessary to set the corresponding ID for the used PP600. For this purpose, use the control display of PP600 and go to Menu > Setting > Pump-ID. Choose [1] that is intended for pH regulation via acid.
8. The setting of the control PBR's software: Select pH Regulator acid in Protocol folder. Choose: Mode = Gas valve and set the target pH value. Upload the setting by **Upload** button.

5.8 EXTERNAL LIGHT PANEL

The Photobioreactor can be supplemented with an additional external light panel that helps to accommodate specific needs of different organisms or to increase illumination intensity.

External light panel is offered in three versions:

- single color,
- single color with additional IR LEDs,
- bicolor.

See chapter 3.1.2 on page 8 for detail list of available versions. Please note that the external LED panel cannot be used simultaneously with the magnetic stirrer. One or the other can be used at one time.

5.8.1 INSTALLATION

Follow instructions below to install and operate the external light panel:

- See the proper position of the holders in Fig. 43A.
- Position the Light Source by inserting its pivot joints into the respective slots in the holders – see Fig. 43B.
- Fig. 43C shows the proper position of the Light Source.

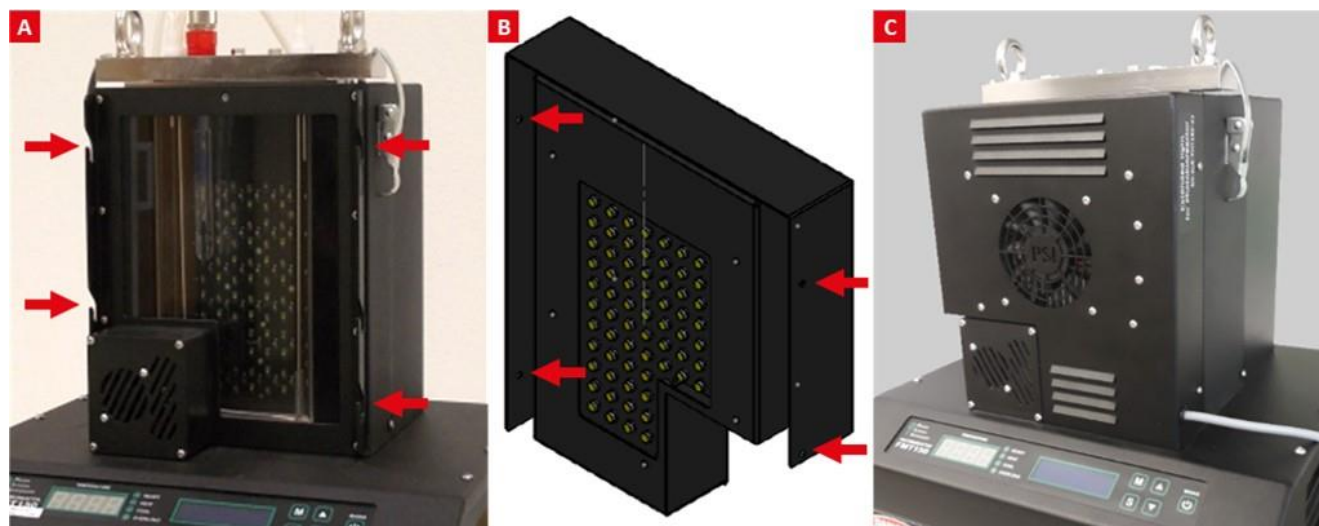


Fig. 43 Correct positioning of the external light panel and the final set-up of the PBR FMT 150 with the external light source.

The function of the external light is controlled manually by the front panel of the PBR control unit or by PBR software. For manual operation via front panel please refer to chapter 7.1 on page 49.

5.9 ADDITIONAL SOFTWARE LICENSE

A separate license is required for each additional PBR software installation.

5.10 LIGHT UPGRADE

Increases intensity of actinic light in the Photobioreactor. The maximum reachable depends on light color as listed on page 8.

5.11 SUPPLEMENTARY/REPLACEMENT COMPONENTS

5.11.1 SUPPLEMENTARY pH/T PROBE

Additional sensor probe to pH/Temperature module.

5.11.2 ADDITIONAL CABLE TO PROBES

Supplementary cable and connector for O₂ or pH/Temperature measuring probe.

5.11.3 SUPPLEMENTARY O₂ PROBE

Additional sensor probe to O₂ module.

5.11.4 O₂ MEMBRANE KIT

O₂ membrane replacement kit for O₂ probe. Includes: 4 membrane bodies, 1 O-ring set, 25 ml electrolyte.

5.11.5 CO₂ MEMBRANE KIT

CO₂ membrane replacement kit for CO₂ probe. Includes: 4 membrane bodies, 1 O-ring set, 25 ml electrolyte.

5.11.6 SUPPLEMENTARY VESSEL (STANDARD MODEL)

Additional vessel, suitable for cultivation in the range of 5 °C – 75 °C (FMT 150/400); 10 – 75 °C (FMT 150/1000 and FMT 150/3000). Made from stainless steel and glass, it includes the frame, lid and glass body. Manufactured in a 400 ml, 1000 ml or 3000 ml version.

5.11.7 ENHANCED VESSEL

Suitable for cultivation in the range of 0 – 75 °C. Made from nickel-plated brass covered with ceramic layer that improves heat convection. Manufactured in a 400 ml, 1000 ml or 3000 ml version.

5.11.8 REPLACEMENT GLASS WINDOW FOR CULTIVATION VESSEL

Includes only the glass body (not the frame, base, or lid). Made of boiling glassware, thickness 3.3 mm. Delivered for 400 ml, 1000 ml or 3000 ml vessels.

5.11.9 GASKET KIT FOR CULTIVATION VESSEL

It includes 5 pcs Silicone gasket for vessel base, 5 pcs Silicone gasket for vessel lid, 5 pcs Silicone O-ring 75/3, 15 pcs Silicone O-ring 16/2. Delivered for 400 ml, 1000 ml or 3000 ml vessels.

6 CULTIVATION GUIDE

This section describes how to set up a standard Photobioreactor FMT 150 and how to initiate cultivation of an algal culture with a PBR software.

6.1 SET-UP THE COMPONENTS

1. First prepare the glass cultivation vessel and its lid. Follow the steps described in chapter 4.2.3 on page 20 to assemble the vessel. Cover the lid of the vessel with aluminium foil and prepare these components for autoclaving.



Never close all three sensor holes with the screws or sensors. It is recommended to leave one sensor hole empty and cover the lid completely with aluminium. Provided sensors can be autoclaved but their lifetime is reduced.

2. Prepare the required medium for autoclaving (volume depends on the vessel capacity).
 3. Prepare all silicone tubes and connectors necessary for gas inlet and gas/medium outlet for autoclaving.
 4. Assemble bubble humidifier bottle as described on Fig. 16 on page 25 and prepare it for autoclaving.
 5. Prepare glass or plastic funnel to be used for pouring of the autoclaved culture medium into the vessel for autoclaving.
- Optional:** Other components need to be autoclaved prior to experiment initiation if other optional components are used together with the standard PBR FMT 150 set up. For example, sampling tube and sampling syringe; additional medium for turbidostat mode; silicone tubes for peristaltic pump and/or magnetic stirring bar if magnetic stirrer is used.
6. Autoclave all components at 120 °C for 20 minutes or according to user's defined protocol.

6.2 SET-UP THE EXPERIMENT

1. Turn ON the PBR FMT 150 main switch on the front panel.
 2. Turn ON the PC and start the PBR client as described in PBR Software manual.
 3. Connect the pH/temperature sensor with the PBR FMT 150.
 4. Before starting new experiment, it is recommended to perform pH sensor calibration with commercial pH standards as described in chapter 4.3.2 or in PBR Software manual. Perform two point calibration with standard pH 7 and pH 10.
- Optionally:** pH calibration can be performed also prior to the vessel autoclaving step. Sensor can be thus autoclaved already inserted in the cultivation vessel.
5. Disconnect the pH/temperature sensor and place it together with the autoclaved cultivation vessel inside a sterile flow hood.
 6. Sterilize the pH electrode with hot or distilled water and mount it immediately in the autoclaved vessel. Other options for sterilization: use 0.1 M HCl or ethanol rinse.
 7. Add medium to the cultivation vessel through the open port for additional probe using sterilized funnel.
- Optional:** If using magnetic stirrer, insert the sterilized magnetic stirring bar into the vessel.
- Optional:** Install other sterilized sensors such as O₂ and CO₂ sensor if required.
8. Close the remaining open vessel ports with autoclaved screws.
 9. Connect all tubing for gas inlet and gas/medium outlet and sampling as described in Fig. 11.
 10. Close all openings, except the one for medium outlet, using sterile connectors.
 11. Take the assembled vessel out of the hood and place it in the PBR, lock it with the side clips. Connect the pH/temperature probe with the PBR (as described in chapter 4.3.1).
 12. **Note:** It is recommended to let the medium in the vessel reach the desired cultivation temperature before proceeding with the next step (calibration).
 13. Prior to start of each experiment OD calibration should be performed with the medium used in that experiment.
- OD calibration can be performed manually on the front panel of the FMT 150 control unit or by PBR software. Please refer to chapter 7.1 on page 49 for manual control or to the PBR Software manual for calibration via software.



Never close all three sensor holes with the screws or sensors. It is recommended to leave one sensor hole empty and cover the lid completely with aluminium. Provided sensors can be autoclaved but their lifetime is reduced.

14. After performing OD calibration add the prepared inoculum solution up to the desired OD value to start the cultivation. Perform this step in the sterile environment of the flow hood.

Optional: User can employ a peristaltic pump to gradually introduce the inoculum into the vessel while monitoring OD of the culture until the desired value is reached for optimal culture initiation.

15. Return the vessel with the culture to the photobioreactor.

16. Connect the vessel with the air line as described on page 26 (Fig. 17).

17. **Note:** If optional accessories are used follow the instructions for their installation.

18. Configure the experimental protocol in the PBR software and start the experiment. Detail description of these steps are available in PBR Software manual.



When using the photobioreactor without the PBR software, follow the manual instructions for the setup of the growth parameters using the front panel of the PBR FMT 150 control unit and as described in chapter 7.1 on page 49.

7 APPENDIX

7.1 FMT 150 CONTROL MENU TREE

This section explains the operation of the Photobioreactor FMT 150 control. Photobioreactor can operate in cultivation mode by setting the cultivation parameters such as light, temperature, etc. in the menu navigation tree. Please note that even though various parameters such as chlorophyll fluorescence and OD, temperature, etc. can be measured, the values and data are not recorded and are only displayed at the time of the measurement. The operation of the PBR control unit is structured into four levels:

1. Main Menu
2. Four Sub-Menus (Measure, Lights, Thermoregulation, Setting)
3. First-level nested structures
4. Second-level nested structures

The following instructions describe operation of the PBR FMT 150 in cultivation mode only.

7.1.1 CONTROL KEYS AND USED SYMBOLS

The Photobioreactor is operated by five keys:

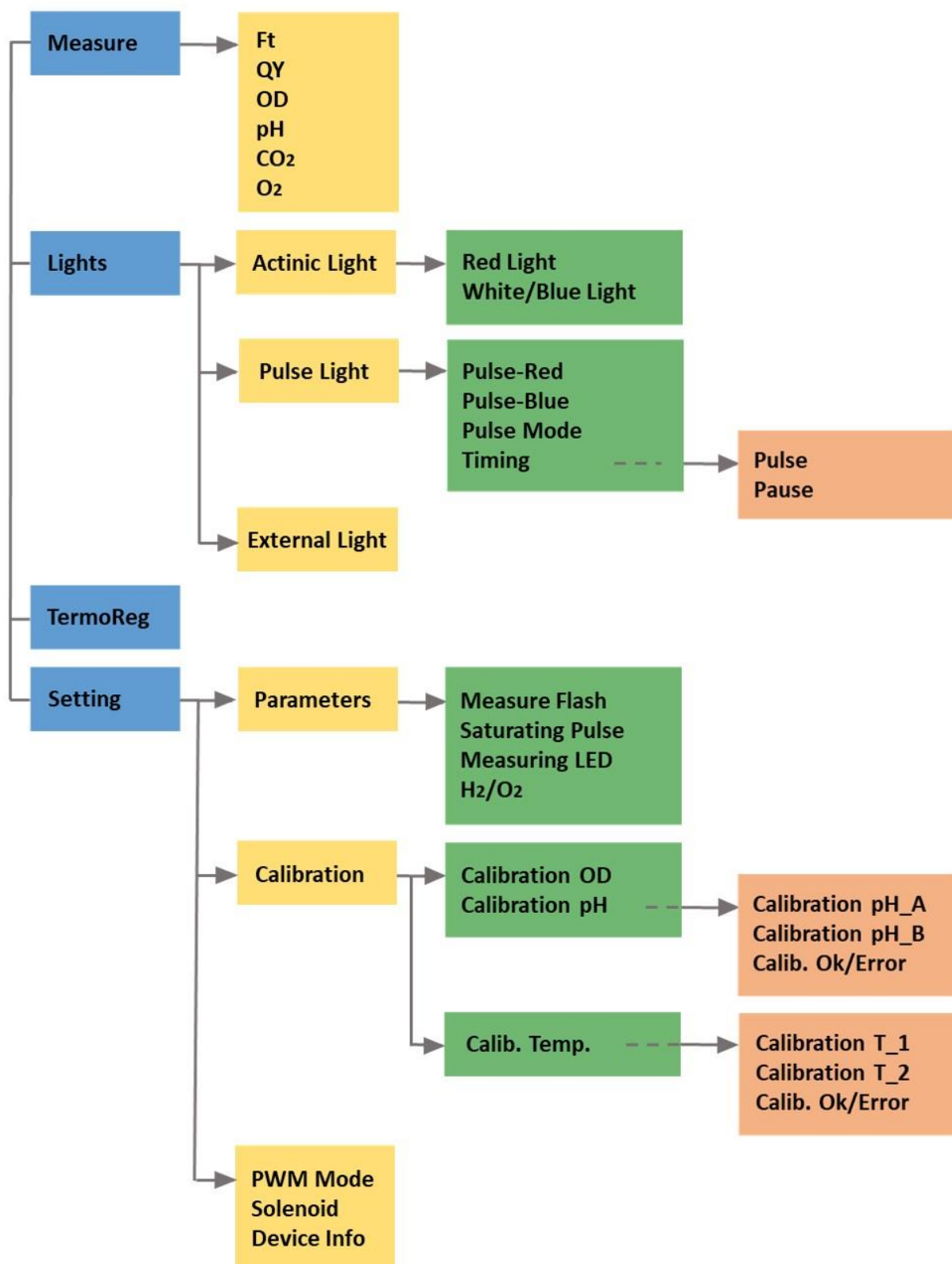
- The **MAINS** key is intended only for service purposes and doesn't have any function related to the common use of PBR. The Photobioreactor is turned on by switching on the corresponding Power supply.
- The **S** key allows to select a submenu and it is also used as a "Confirm Selection" key. Long pressed **S** key (= **HS**) is mostly used for moving inside the single menus (scrolling).
- The **M** key allows moving back to a parent menu.
- The two **Scroll** keys allow moving up and down inside the single menu.

Explanation of symbols and color differentiation used in the schematic (the display of the Photobioreactor does not reflect this color differentiation):

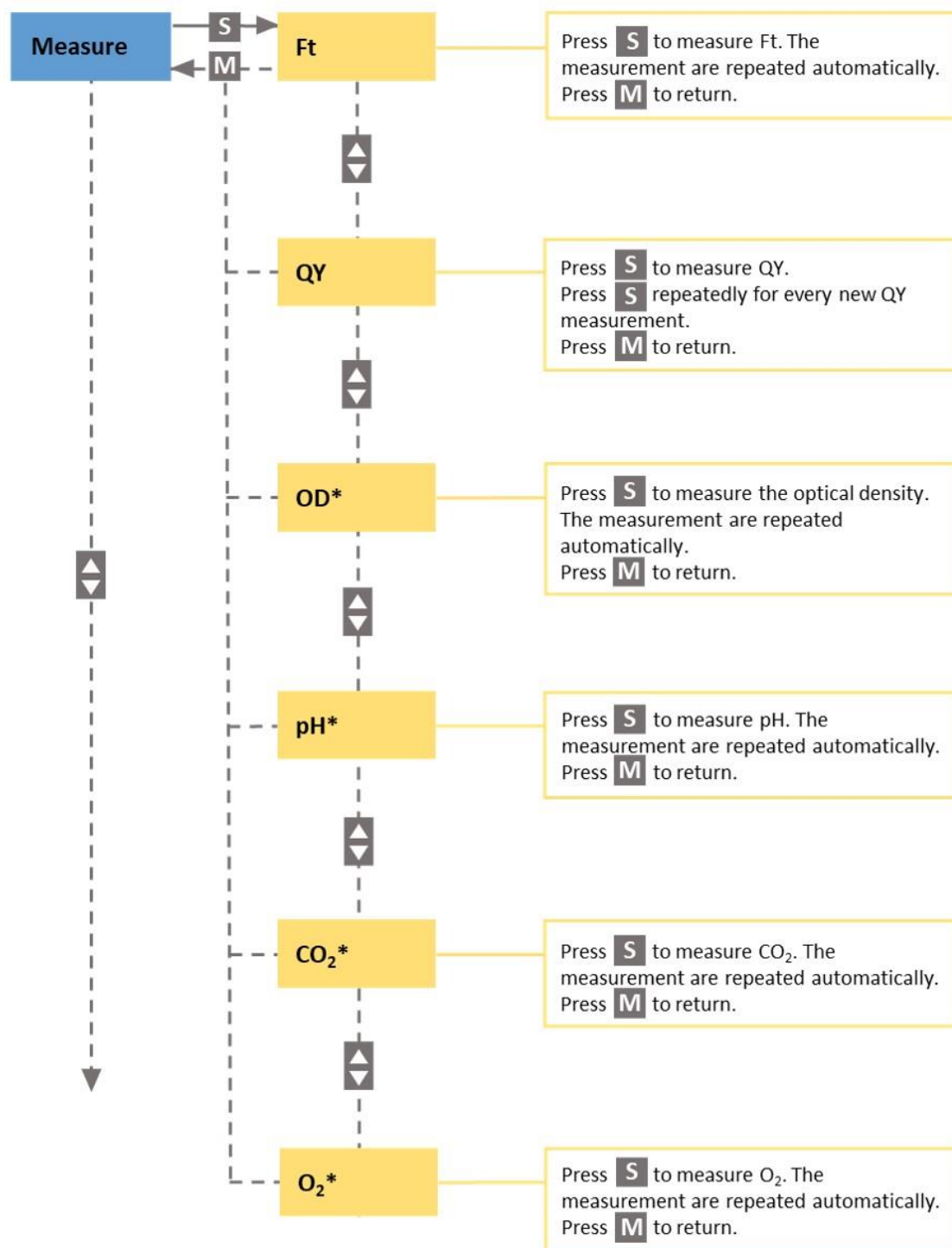
- **SET** key (short press)
- **MENU** key (short press)
- **UP/DOWN** key
- **Hold SET** key = **SET** key (long press)
- **SET** key (short press or long press)
- **Hold MENU** key = **MENU** key (long press)
- **MENU** key = (short press or long press)
- Full-line arrows are used for the **S** key.
- Dashed-line arrows are used for the **M** key.
- Dotted-line arrows are used for the **UP/DOWN** key.
- **Blue** color represents the **Main Menu**.
- **Yellow** color represents the **Sub-Menu** items.
- **Green** color corresponds to the **first-level nested structures**.
- **Orange** color corresponds to the **second-level nested structures**.

7.1.2 OPERATION SCHEMATIC

Menu Tree - Main



Measure Sub-Menu



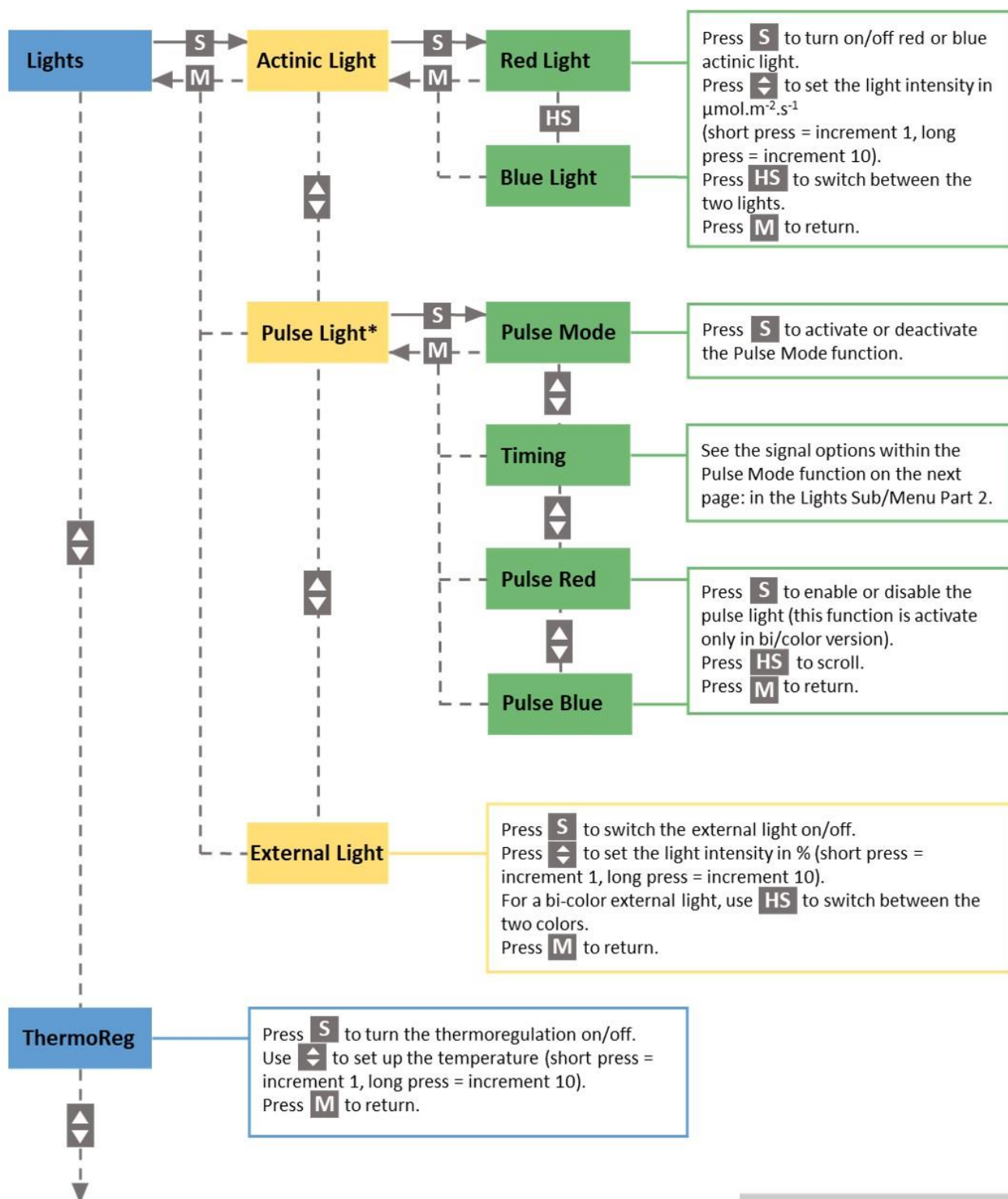
*** Abbreviations explanation:**

[CAL] = OD / pH calibrated

[NCL] = OD / pH not calibrated

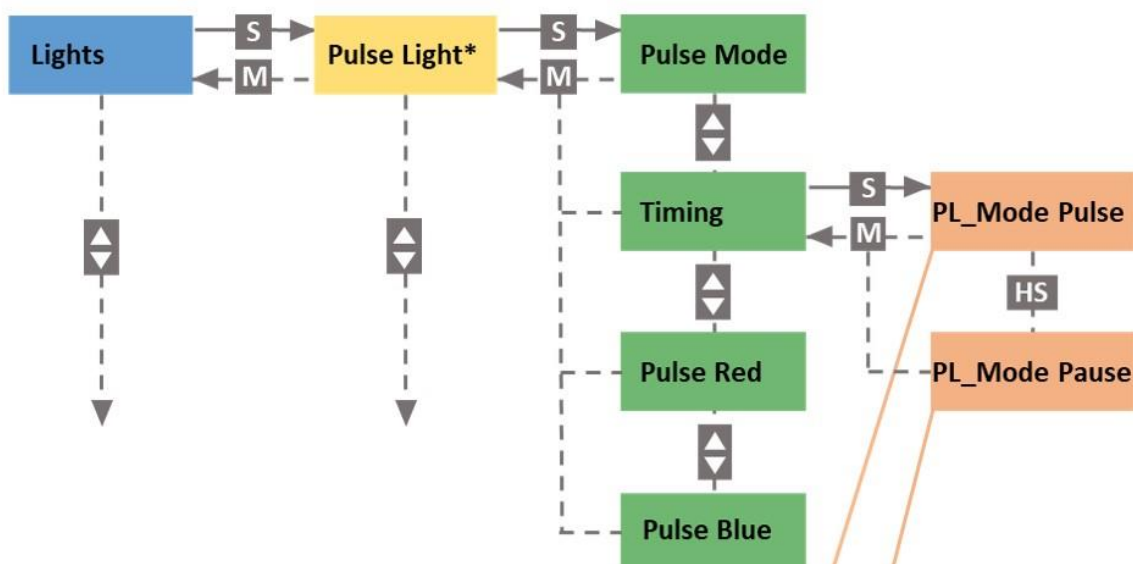
[Dis] = CO₂ / O₂ module disabled

Light and Thermoregulation Sub-Menu



* See more detailed information on the Pulse Light Mode in Chapter Appendix 3 of this manual.

Light Sub-Menu (Part 2)



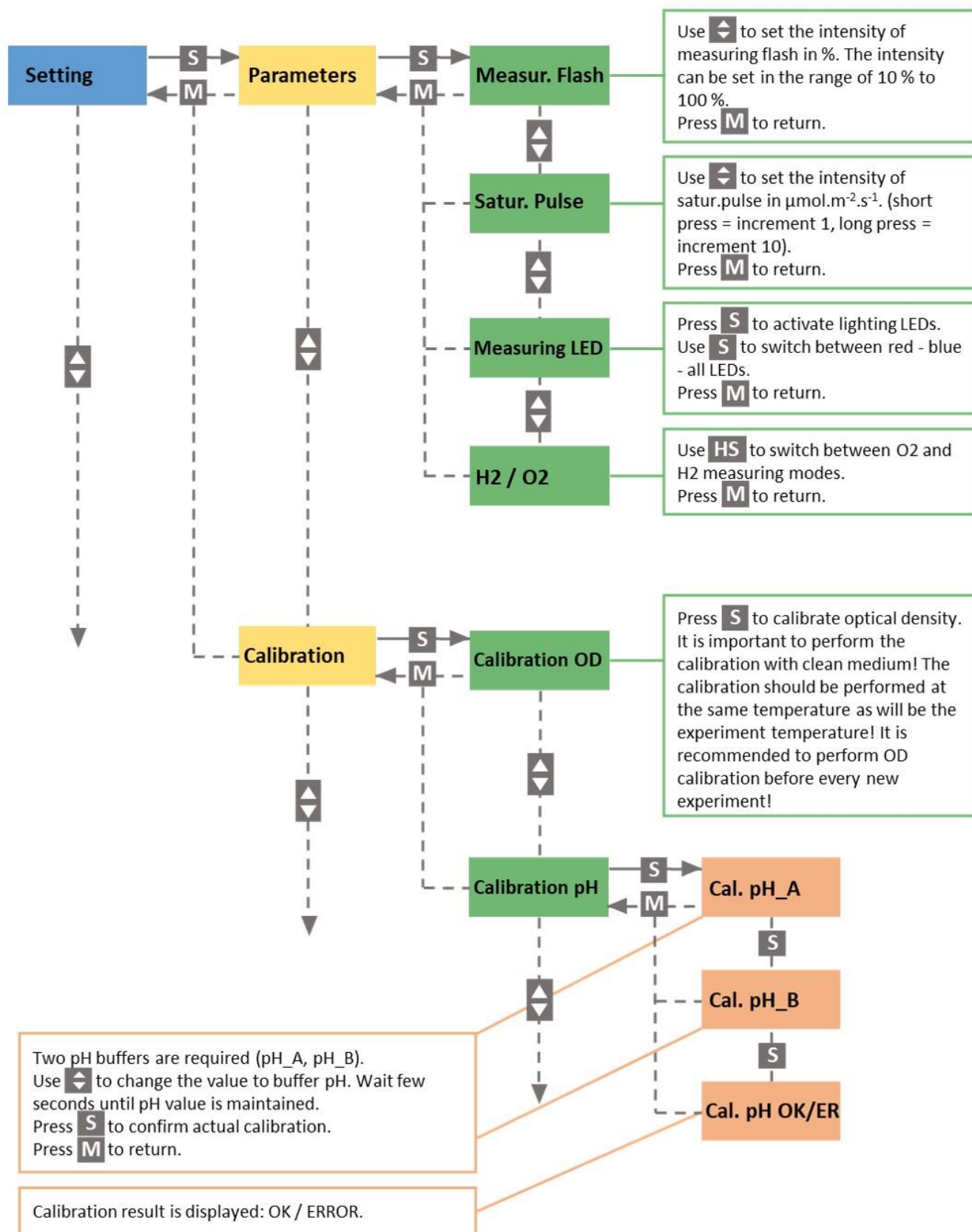
Press **S** for setting the pulse time interval (pulse width).
 Press **↕** to set the pulse time interval in format: SECOND : MILLISECOND : MICROSECOND (second <0;3600>; millisecond <0;999>; microsecond <0;900>).
 Press **HS** to scroll.
 Press **M** to return.

Press **S** for setting the pause time interval (pause width).
 Press **↕** to set the pulse time interval in format: SECOND : MILLISECOND : MICROSECOND (second <0;3600>; millisecond <0;999>; microsecond <0;900>).
 Press **HS** to scroll.
 Press **M** to return.

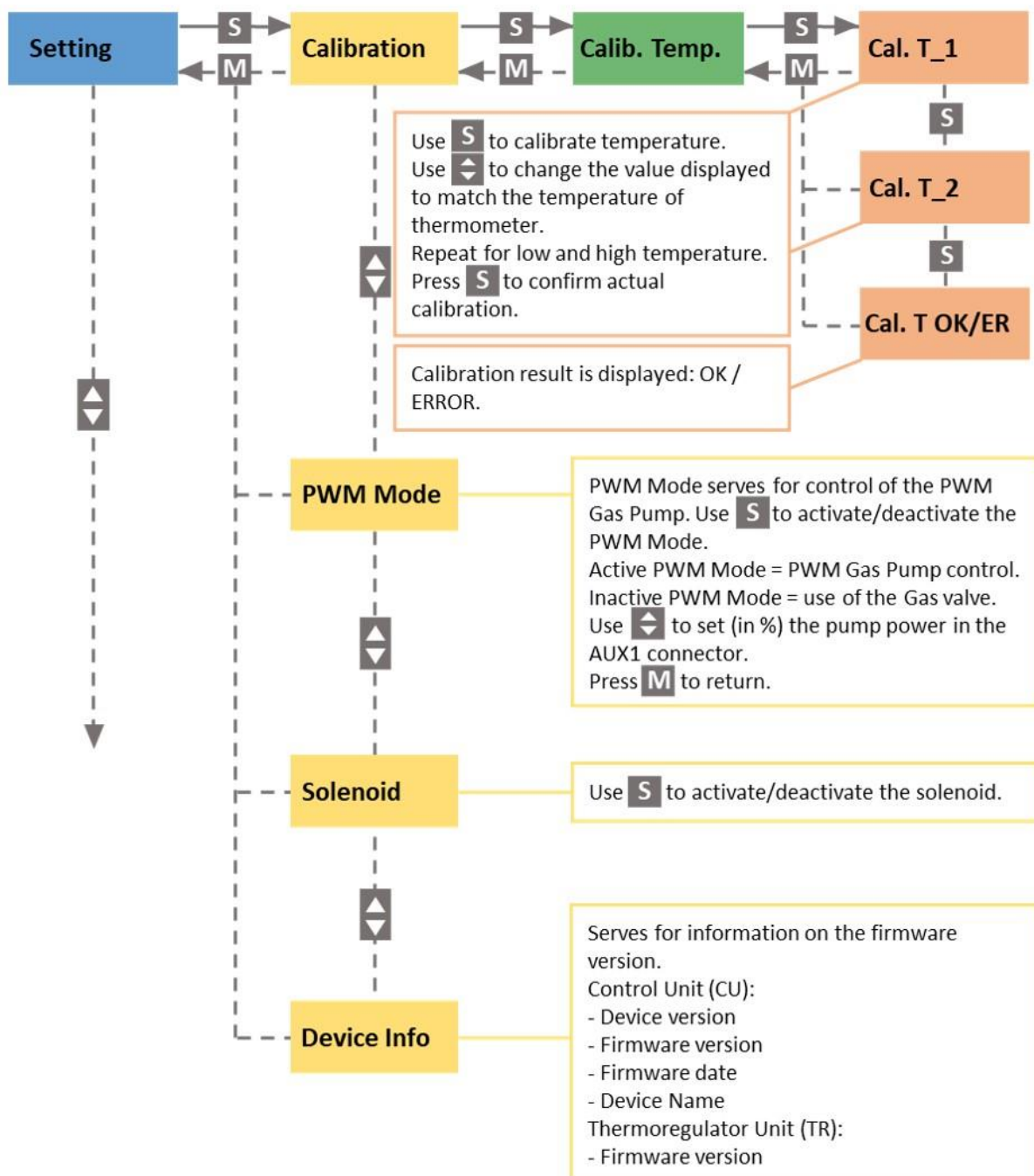
* See more detailed information on the Pulse Light Mode in Chapter Appendix 3 of this manual.



Setting Sub-Menu (Part 1)



Setting Sub-Menu (Part 2)



7.1.3 PULSE LIGHT CONTROL

Pulse light control mode is designed to study the response of the cultivated culture to rapidly repeated flashes of actinic lights (red, blue or white combination depending on purchased combination of actinic lights).

Control keys used are described in detail in Appendix on page 49.

Note: Please note that the Pulse Light Control protocol can be operated only via front panel of the PBR FMT 150 control unit and is currently not supported in PBR software.

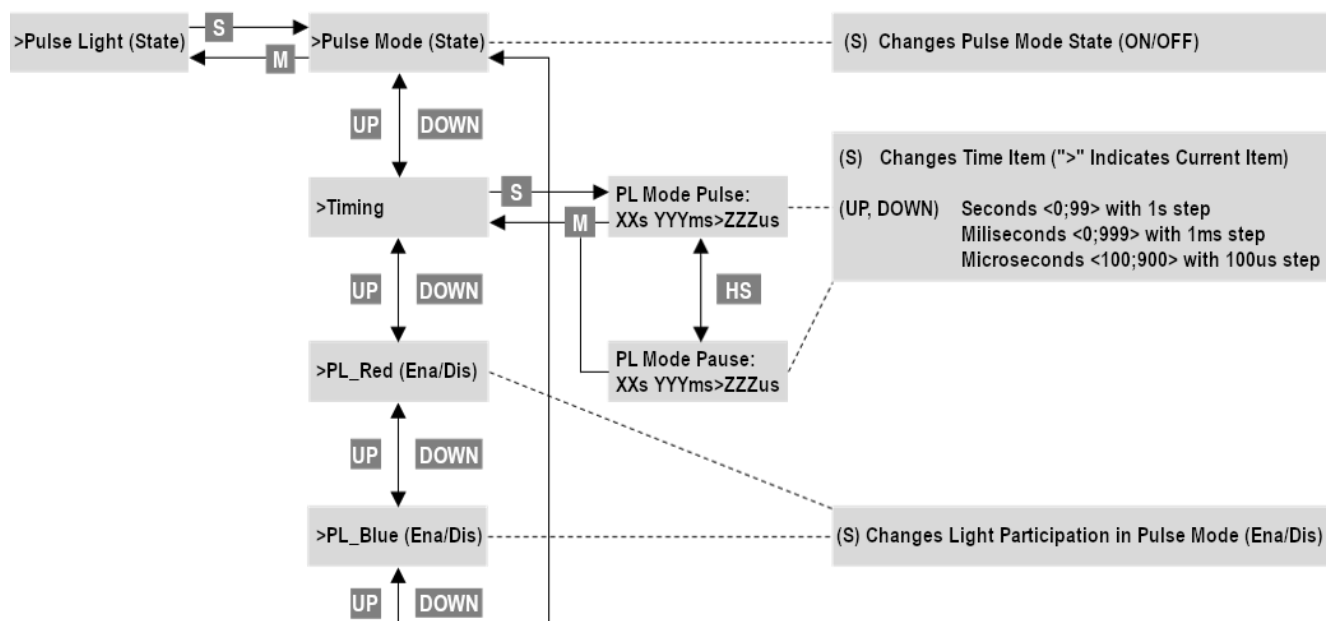


Fig. 44 Pulse light menus.

7.2 QY MEASUREMENT

Below is shown schematic description of the QY measurement.

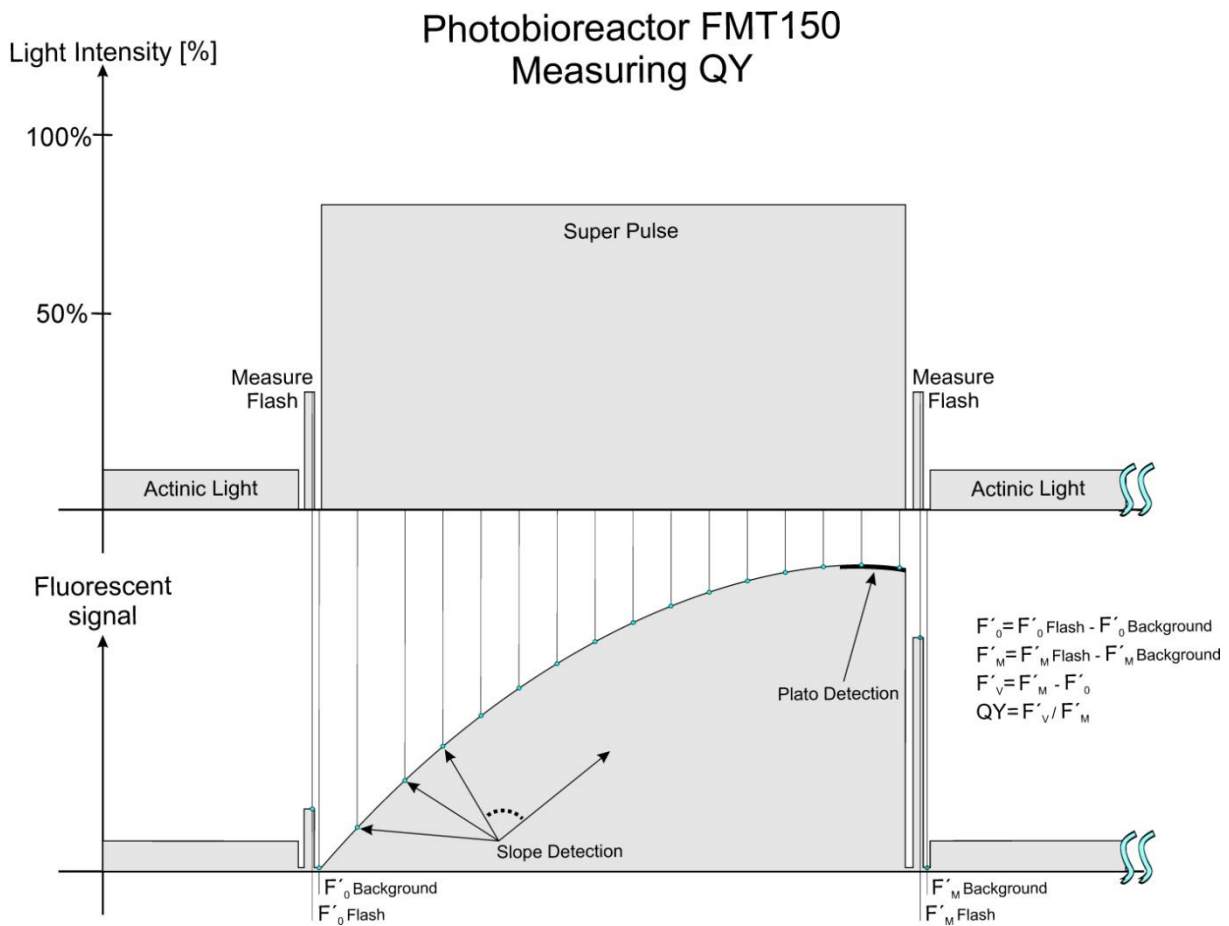


Fig. 45 QY measurement theory.

7.3 TECHNICAL SPECIFICATION STANDARDS

Cultivation Vessel		
Volume	400 / 1000 / 3000 ml (FMT 150/400, FMT 150/1000, FMT 150/3000)	
Shape	Flat, rectangular	
Dimension (h x l x d) / Weight	23.9 x 19.3 x 3.7 cm / 2.8 kg (FMT 150/400) 23.9 x 19.3 x 7.4 cm / 3.8 kg (FMT 150/1000) 31.7 x 30.3 x 7.4 cm / 6.2 kg (FMT 150/3000)	
Material	Glass, stainless steel bottom, silicon gasket, autoclavable	
Lid	Stainless steel 3 big ports for sensors, 4 small Luer connectors for tubing (Ø 6/3 mm) (FMT 150/400 and FMT 150/1000) 4 big ports for sensors, 8 small Luer connectors for tubing (Ø 6/3 mm) (FMT 150/3000)	
Aeration tubes	Stainless steel U-tube with aeration holes (Ø 1 mm) + silicon connection	
Humidifier	Moistening of the sparging air to avoid evaporation from the cultivation vessel	
Sampling	Through the inlet or outlet tubes	
Thermoregulation		
Thermoregulation system	200 W Peltier element (FMT 150/400 and FMT 150/1000) 400 W Peltier (FMT 150/3000)	
Range (ambient temperature around 23 °C)	5 – 75 °C (FMT 150/400) 10 – 75 °C (FMT 150/1000 and FMT 150/3000)	
Illumination - LED Lighting		
Light panel		
Color version	Cool White - Red or Blue - Red Other color combination on request	
Total intensity	Up to 1,500 µmol. m ⁻² . s ⁻¹	Up to 3,000 µmol. m ⁻² . s ⁻¹ (optional with Light Upgrade)
Light path	24 mm (FMT 150/400) 61 mm (FMT 150/1000 and FMT 150/3000)	
Light regime	Light / dark cycles Constant, Linear, Sinusoid light mode Cycles from seconds up to days	Java scripting (advanced PBR control SW)
External light panel	Mounted on the front side, up two colors (optional)	
Aeration System		
Air sparging	Aeration pump	
Aeration tubes	Stainless steel U-tube with aeration holes (Ø 1 mm) + silicon connection	
Bubble interruption valve	Connectors for silicone tubing (Ø 6/3 mm) Automatic bubbling interruption during OD and Chlorophyll-a fluorecence measurement	
Gas Mixing System GMS 150	For precise concentration and flow rate of the aeration gases, gas cylinders not included (optional)	

8 LIST OF FIGURES

Fig. 1 Device description.....	7
Fig. 2 Schematic diagram of the Photobioreactor, its modules and remote control.....	8
Fig. 3 LED spectra of PBR FMT 150.	9
Fig. 4 Components of the Spare Part Kit.....	11
Fig. 5 Photobioreactor front panel.	13
Fig. 6 PBR FMT 150 control unit and its power supply rear panel.....	14
Fig. 7 Schematic of recommended set-up for interconnecting available modules with PBR FMT 150 control unit.....	16
Fig. 8 Connection of the Photobioreactor and the power supply.....	17
Fig. 9 Schematic design of the PBR cultivation vessel types.....	18
Fig. 10 Components of the 400 ml cultivation vessel.	19
Fig. 11 Assembly of the vessel lid.	21
Fig. 12 Components of 3000 ml cultivation vessel.	22
Fig. 13 pH/temperature module.....	23
Fig. 14 Installation of the pH/temperature sensor.	23
Fig. 15 Older version pH sensor calibration.....	24
Fig. 16 Assembly of the bubble humidifier bottle.....	25
Fig. 17 FMT 150 set-up with air pump supplying the gas.	26
Fig. 18 Remote Control System for PBR FMT 150.....	27
Fig. 19 O ₂ module.	27
Fig. 20 Installation of the O ₂ sensor.....	28
Fig. 21 Digital CO ₂ Module.....	29
Fig. 22 Assembly of the CO ₂ electrode.	29
Fig. 23 Installation of the CO ₂	30
Fig. 24 Magnetic stirrer.....	31
Fig. 25 Relation between rotation speed in rpm and PWM value in % adjusted by the PBR.	32
Fig. 26 Components for the magnetic stirrer.....	32
Fig. 27 Screws for fixing the stirrer to the front side of the PBR main body.....	33
Fig. 28 Magnetic stirrer is fastened in the correct position to the front part of the PBR.	33
Fig. 29 Attaching of the AUX cable (A, B) and manual control (C) of magnetic stirrer.	34
Fig. 30 PWM Pump.	34
Fig. 31 PWM Pump control and connection.	35
Fig. 32 GMS 150.....	36
Fig. 33 GM System connection with the PBR FMT 150.....	37
Fig. 34 Scheme for connecting more PBR FMT 150 units to one GM System.....	38
Fig. 35 Peristaltic pump PP600.	39
Fig. 36 Assembly of the peristaltic pump.....	40
Fig. 37 Final assembly of the peristaltic pump.	41
Fig. 38 Connection of peristaltic pump with PBR FMT 150.....	42
Fig. 39 pH stat kit.	42
Fig. 40 Connection of peristaltic pump and pH stat kit with PBR FMT 150.	43
Fig. 41 Connection of Parker tubing to the pH stat kit.	44
Fig. 42 Final assembly of the pH stat module.	44
Fig. 43 Correct positioning of the external light panel and the final set-up of the PBR FMT 150 with the external light source.	45
Fig. 44 Pulse light menus.	58
Fig. 45 QY measurement theory.....	59

9 WARRANTY CONDITIONS

1. Photon Systems Instruments, Ltd. (PSI) warrants all its instruments to be free from defects in materials or workmanship for a period of **one year** from the date of invoice/shipment from PSI. Warranty term for the European Union member states is **two years**.
2. If at any time within this warranty period the instrument does not function as warranted, return it and PSI will repair or replace it **at no charge**. The customer is responsible for shipping and insurance charges (for the full product value) to PSI. PSI is responsible for shipping and insurance on return of the instrument to the customer.
3. No warranty will apply to any instrument that has been (i) modified, altered, or repaired by persons unauthorized by PSI; (ii) subjected to misuse, negligence, or accident; (iii) connected, installed, adjusted, or used otherwise than in accordance with the instructions supplied by PSI.
4. The warranty is return-to-base only, and does not include on-site repair charges such as labor, travel, or other expenses associated with the repair or installation of replacement parts at the customer's site.
5. PSI repairs or replaces the faulty instruments as quickly as possible; maximum time is one month.
6. PSI will keep spare parts or their adequate substitutes for a period of at least five years.
7. Returned instruments must be packaged sufficiently so as not to assume any transit damage. If damage is caused due to insufficient packaging, the instrument will be treated as an out-of-warranty repair and charged as such.
8. PSI also offers out-of-warranty repairs. These are usually returned to the customer on a cash-on-delivery basis.
9. **Wear & Tear Items** are excluded from this warranty. The term **Wear & Tear** denotes the damage that naturally and inevitably occurs as a result of normal use or aging even when an item is used competently and with care and proper maintenance.
10. Some PSI instruments use accessories made by other manufacturers. In such case, these accessories may be covered by a different warranty period.
11. Contact us at support@psi.cz in case of any support with the assembly and installation of the device is needed.