

**Gas-Exchange Chamber
(3010-GWK1)
Manual**

2nd edition

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Heinz Walz GmbH • Eichenring 6 • 91090 Effeltrich • Germany
Phone +49-(0)9133/7765-0 • Telefax +49-(0)9133/5395
E-mail info@walz.com • Internet www.walz.com

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1 Safety Instructions

1. Read the safety instructions and the operating instructions first.
2. Pay attention to all the safety warnings.
3. Keep the device away from water or high moisture areas.
4. Keep the device away from dust, sand and dirt.
5. Always ensure there is sufficient ventilation.
6. Do not put the device anywhere near sources of heat.
7. Connect the device only to the power source indicated in the operating instructions or on the device.
8. Clean the device only according to the manufacturer's recommendations.
9. Ensure that no liquids or other foreign bodies can find their way inside the device.
10. The device should only be repaired by qualified personnel.
11. The Gas-Exchange Chamber (3010-GWK1) is a highly sensitive research instrument, which should be used only for research purposes, as specified in this manual. Please follow the instructions of this manual in order to avoid potential harm to the user and damage to the instrument

2 Introduction

The Gas-Exchange Chamber 3010-GWK1 is designed to enable gas exchange measurements of plant material in a climate controlled environment. Fig. 1 shows the base of the Gas-Exchange Chamber 3010-GWK1. Fig. 2 shows the view from underneath.

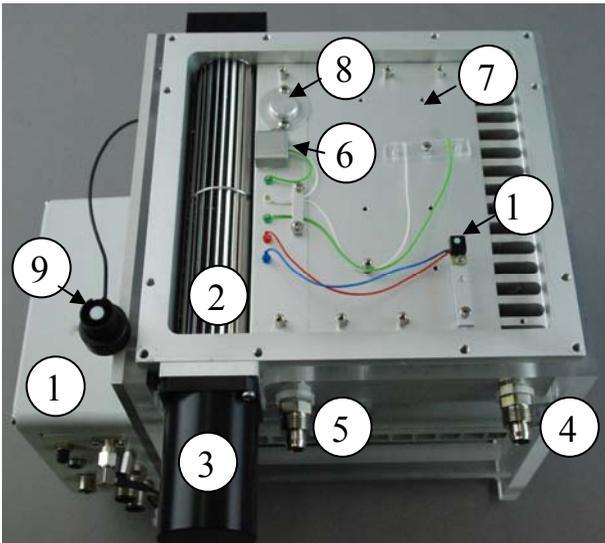


Fig. 1 Gas Exchange Chamber GWK1; Base, top-view

1. Electronics box
2. Inside fan
3. Motor for inside fan
4. Air inlet
5. Air outlet
6. Tcuv: Pt100 measuring cuvette temperature
7. Tleaf: thermocouple measuring leaf temperature
8. RH: relative humidity sensor (underneath cover)
9. PARamb: Micro Quantum Sensor (MQS/B) measuring cosine corrected ambient photosynthetically active radiation (PAR)
10. PARtop: measuring internal PAR

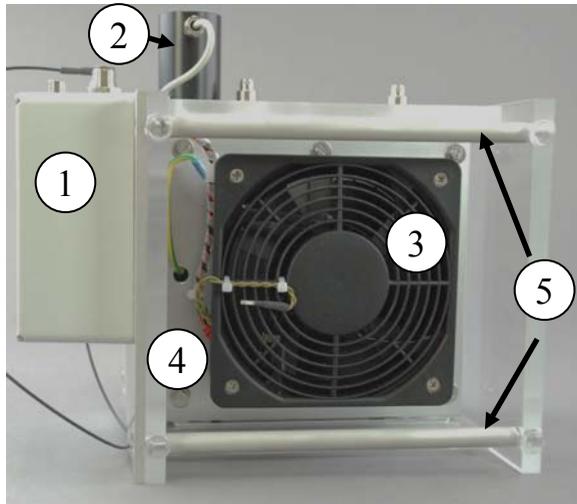


Fig. 2 Gas Exchange Chamber GWK1;
View from underneath

1. Electronics box
2. Motor for inside fan
3. Fan for heat exchange of Peltier elements
4. Tamb: Pt-100 sensor for ambient temperature
5. use these bars, when carrying the Gas-Exchange Chamber 3010-GWK1

The connectors of the Gas Exchange Chamber 3010-GWK1 are shown in Fig. 3.



1. Trigger button for data storage
2. Status-LED (green blinking: ok)
3. Connector COMP, to which additional components developed by Walz can be connected. If the Gas Exchange Chamber 3010-GWK1 is operated without GFS-3000, an optional USB-interface to a computer can be connected here.
4. Connector for PARamb-sensor
5. Connector for light source (not available)
6. Connector for GFS-3000
7. Connector for power supply

Fig. 3 Connectors

3 Operation

3.1 Setting up the System

To set up the GFS-Win software, see manual of the GFS-3000.

3.2 Starting the Software

In GFS-Win switch the Measure Mode on (*System/ Measure Mode on*) to establish the USB-connection and switch the system on. When

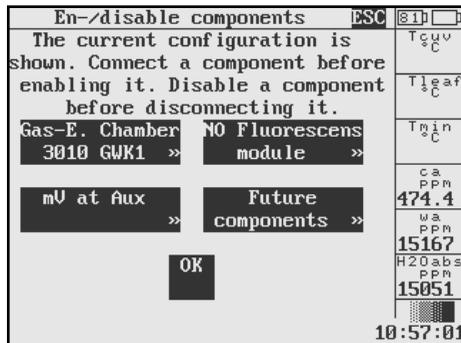
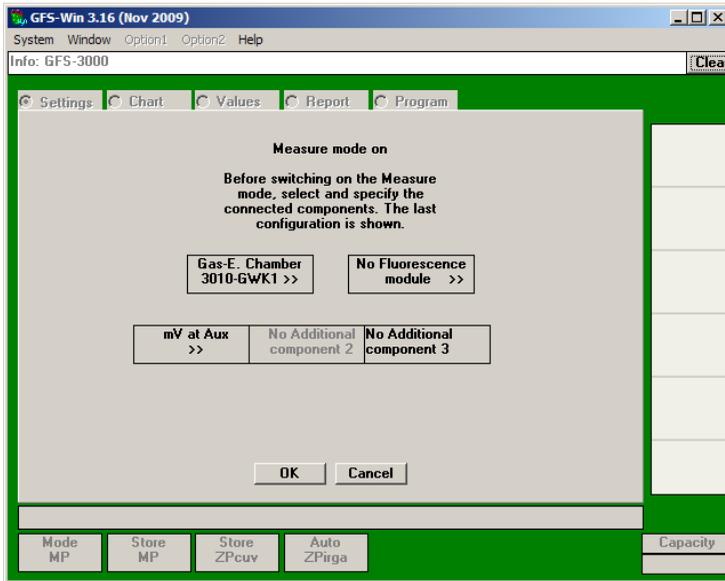


Fig. 4 Choosing the Gas-Exchange Chamber 3010-GWK1 in GFS-Win and on the Panel-PC

operating the system with the panel-PC, use the same command: *System/Measure Mode on*. If the chamber is directly connected to a computer with the optional interface 3010-I/GWK (no GFS-3000 used), start the measurement in GFS-Win with *System/Measuring Head only ON*.

A window will appear where the measuring head can be enabled. Choose the Gas-Exchange Chamber 3010-GWK1 and press OK (see Fig. 4).

3.3 New Parameters for the Gas-Exchange Chamber 3010-GWK1

When the Gas-Exchange Chamber 3010-GWK1 is connected there appear several parameters, which do not appear with the Standard Measuring Head 3010-S.

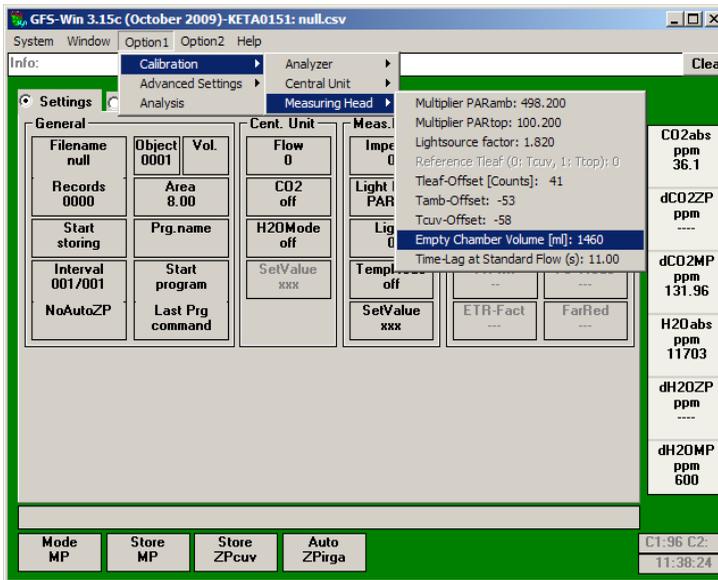
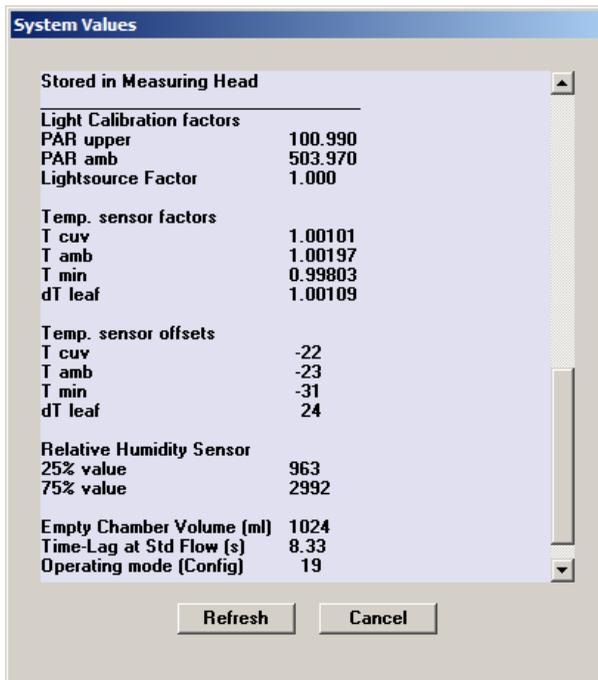


Fig. 5 GFW-Win showing the parameters, which are stored in the Electronic Box of the Gas-Exchange Chamber 3010-GWK1 and can be changed by the user

The first parameter is the volume of the empty gas exchange chamber annotated Empty Chamber Volume (Fig. 5). This parameter is



System constants		ESC	81	D
dH2O_Cal: 5000	dco2_Cal: 5010	Tcuv	27.68	
H2O_Quer: 3513		Tleaf	27.48	
Time-Lag at Std.Flow: 8.33s		Tmin	27.69	
Tcuv_o : -22	Tcuv_g : 1.00101	ca	488.1	
Tamb_o : -23	Tamb_g : 1.00197	wa	16316	
Tmin_o : -31	Tmin_g : 0.99803	H2O abs	16312	
Tleaf_o : 24	Tleaf_g : 1.00109			
PARamb_g: 503.970				
PARtop_g: 100.990				
RH 25% : 963	RH 75% : 2992			
Lights_f: 1.00000				
Empty Chamber Volume : 1024ml				
Reserve1: 1.00000				
Min.Light=222h	Max.Light=DACH			12:53:45

Fig. 6 Option2/ System Constants showing the parameters, stored in the Electronics Box of the Gas-Exchange Chamber 3010-GWK1. Top: in GFS-Win; bottom: on the panel-PC

stored in the Gas-Exchange Chamber 3010-GWK1. It needs to be changed, if the upper part of the chamber is altered, so that the volume changes. To access it, chose *Calibration/Measuring Head/Empty chamber Volume* in GFS-Win.

Since the values are stored in the measuring head, the Gas Exchange Chamber 3010-GWK1 can simply be replaced by the Standard

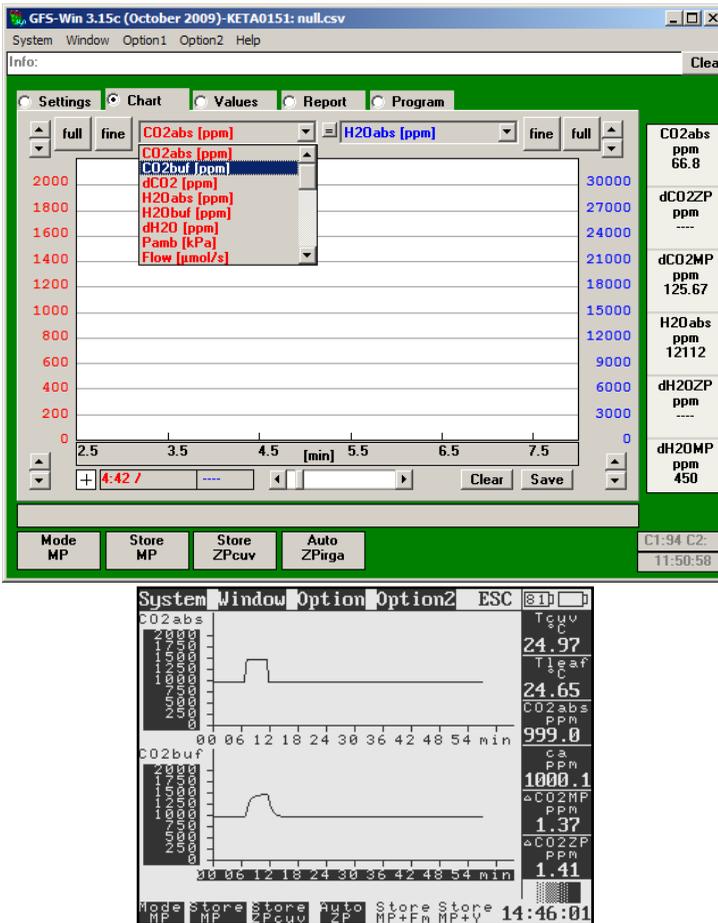


Fig. 7 GFS-Win and the panel-PC with window chart showing the new variables CO2buf and H2Obuf

Measuring Head 3010-S or the Dual-PAM Cuvette 3010-Dual without concern on any settings. Only the valve settings of the Central Unit need to be readjusted, if the measuring head or the flow rate is changed.

The chamber volume is required to calculate the new variables CO2buf and H2Obuf (Fig. 7). These are the CO₂ or H₂O mole fractions the gas exchange chamber would reach, if it was empty. These concentrations are calculated from the flow rate, the chamber volume, and the continuously recorded concentrations in the reference, CO2abs and H2Oabs, with an e-function. If the volume of the sample reduces the chamber volume by a considerable amount (e.g. when measuring fruits), its value needs to be entered correctly in the windows settings before the experiment (Fig. 8). The calculation of the parameters CO2buf and H2Obuf enables the calculation of dCO2MP and dH2OMP more correctly, even before the cuvette is completely flushed and in a new steady state after a change in concentration settings. When the system is in a complete steady state, CO2buf and H2Obuf will become equal to CO2abs and H2Oabs. If the entered volume is wrong, dCO2MP and dH2OMP can still be correct, but the user needs to wait longer for a steady state. Since the calculation of CO2buf and H2Obuf requires the continuously recorded data, it is not possible to recalculate the data with a new volume after the measurement.

The new variables CO2buf and H2Obuf are only shown in the Window/Chart. They are not stored or indicated in the values window, since they are only used internally for the calculation of dCO2MP and dH2OMP. CO2buf and H2Obuf can easily be recalculated from dCO2MP, ca, dH2OMP and wa (see chapter 4).

Note, that with the panel-PC, if *Option /Data-File Management or Program-File Management* is chosen, the measurement is interrupted, so that the calculation of CO2buf and H2Obuf is interrupted, too, even though the system is running. Avoid using these functions during

measurements or wait until the system is in a steady state after using these functions before taking measurements.

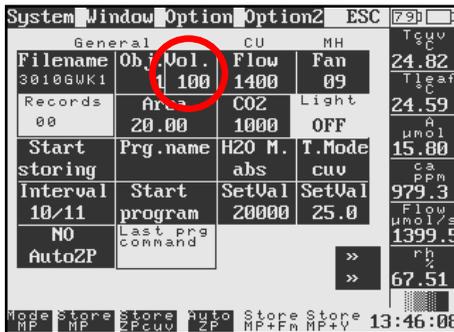
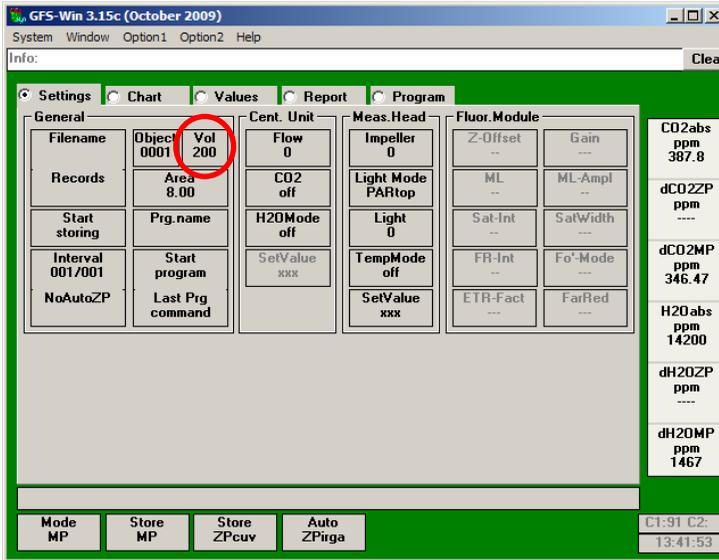


Fig. 8 GFS-Win and panel-PC with window settings showing the new parameter Vol, which is the estimated sample volume, reducing the chamber volume

Also the values CO₂ sam (CO₂ concentration in the sample side of the analyzer) and H₂O sam (H₂O concentration in the sample side of the analyzer) are not shown. Instead the values ca and wa, that are the same as CO₂ sam and H₂O sam, but corrected for dCO₂ZP and dH₂OZP,

respectively, are shown and stored. The names ca and wa indicate, that they are the concentrations of CO₂ and water around the sample in contrast to ci, which is the intercellular CO₂-concentration. See also chapter 4 for a mathematical description of these parameters.

Another parameter stored directly in the electronics of the measuring

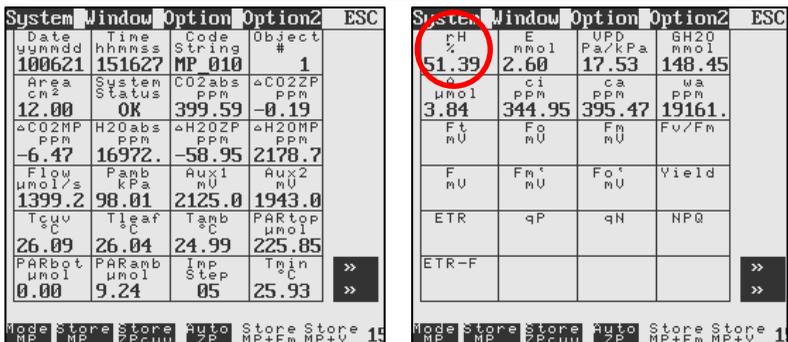
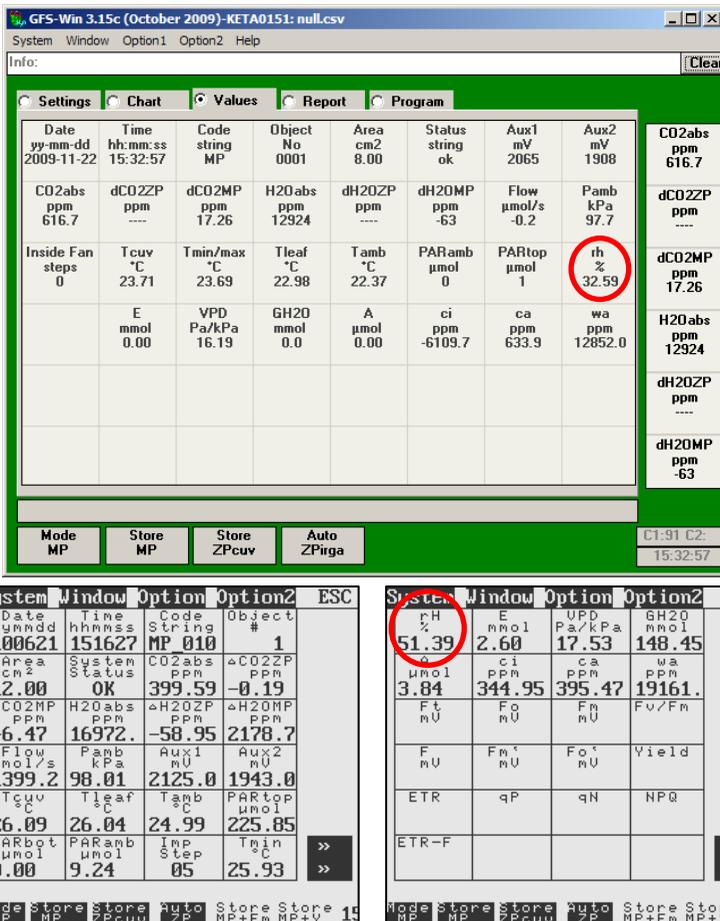


Fig. 9 Window values in GFS-Win and on the panel-PC, the relative humidity (rh) is measured with an RH-sensor within the Gas-Exchange Chamber 3010-GWK1

head with *Option1/ Calibration/ Measuring Head* is the “Time-Lag at Standard Flow (s)” (Fig. 5 and Fig. 6). This parameter is affected by the tube length. It is used to take the time-lag between the air coming through the measuring head and through the reference channel into account. The actual parameter used for the data calculation is called “CO2delay”. In GFS-Win, it can be seen in *Option1/Advanced Settings*. CO2delay is calculated from the time-lag, stored in the measuring head, and the chosen flow rate whenever the flow is switched on or changed. If there is no measuring head connected, the CO2delay can be adjusted under advanced settings in GFS-Win.

The Gas Exchange Chamber-GWK1 has a sensor for relative humidity. The indicated value is not calculated as for the Standard Measuring Head 3010-S, but measured within the cuvette (see Fig. 9).

3.4 Starting Gas Exchange Measurement

3.4.1 Checks before Gas Exchange Measurement

Read chapter 6 of the GFS-3000 manual for a short reminder on the checks and calibrations that might be required before a gas exchange measurement can be started.

Check whether the silica gel within the Gas Exchange Chamber 3010-GWK1 needs to be replaced. It prevents condensation at the electronics, which is especially required, when the cooling function is used during the experiment.

3.4.2 Setting-Up and Starting the Gas Exchange Measurement

When the Gas-Exchange Chamber 3010-GWK1 is connected and GFS-Win is started, the volume of the sample (ml) appears in the window settings as additional parameter (Fig. 8). Enter the volume of the sample. If the upper part of the chamber has been changed, make sure that the volume of the empty chamber (*Option/Calibration/*

Measuring Head/Empty Chamber Volume), which is stored in the electronics box of the chamber, is correct.

Decide on the flow; the standard value for the Gas-Exchange Chamber 3010-GWK1 is 1250 $\mu\text{mol/s}$. With this flow, adjust the valves of the GFS-3000 with a small screw driver. To do that, press *Option1/Calibration/Central Unit/Valve Adjustment* in GFS-Win and follow the given instructions. Usually, the valve adjustment only needs to be performed once after the cuvette or the flow has been changed between experiments.

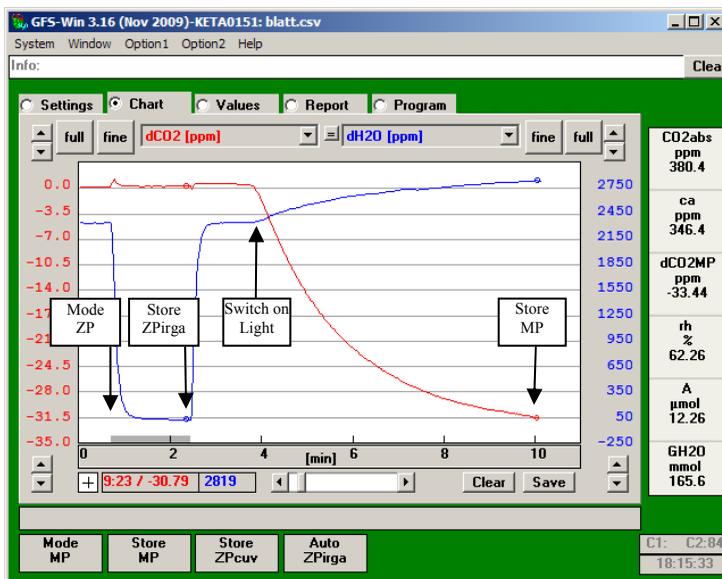


Fig. 10 Determination of differential zero for H₂O and CO₂ (dCO₂ZP_i, dH₂OZP_i) and start of a measurement

After switching the system on, enter the set-point for the cuvette temperature and speed of internal fan, switch on the flow, choose the CO₂ and H₂O concentration, enter the reference magnitude of the sample (area or weight), and finally enter a filename for the data storage.

For accurate gas exchange measurements, it is essential to measure the zero for the differential CO₂ and H₂O concentration before the CO₂ assimilation or H₂O evaporation can be measured. This can be done using the ZP Mode or with an empty cuvette. Fig. 10 shows an example, where the Zero Point has been determined in ZP-Mode. Further information on MP and ZP Mode can be found in the GFS-3000 manual. (chapter 4.3). It is advisable to repeat the complete measurement procedure with an empty chamber to get an idea of the influence of diffusion processes on the measurement. The differential zero depends on the absolute concentration of CO₂ or H₂O and may drift with time.

Opening the chamber will disturb the CO₂ and H₂O concentrations in the chamber. It will take a while until the gas exchange measurement is in a steady state.

Each time after inserting a sample, check whether the chamber is closed properly (check the mechanical flow indicators). If it is not possible to seal the chamber properly (e.g. around the petiole), Terostat IX (Fig. 11) might be helpful.

Do not compress the gaskets, when storing the chamber.



Fig. 11 Label of Terostat IX, a sealing material commonly used in gas exchange measurements or in car repairs

4 Calculations

4.1 Parameters for Calculations

The following table (Table 1) lists the parameters integrated in the formulas and directly assessed by the GFS-3000 when the Gas Exchange Chamber 3010-GWK1 is connected.

Table 1: Parameters used for calculation

Given parameter or measured value	Description	Unit
Empty Chamber Volume	Volume of the empty chamber	ml
Vol	Sample Volume	ml
CO2delay	Time difference between the gas arriving in the sample or reference side of the gas analyzer	s
Area/Weight	Reference value of the sample used for calculations	cm ² /mg
CO2abs	CO ₂ mole fraction in reference cell of analyzer, equal to CO ₂ concentration at inlet of cuvette.	ppm*
CO2sam	CO ₂ mole fraction in sample cell of analyzer. Not corrected for dCO2ZP	ppm
dCO2ZP	= CO2sam - CO2abs (in Mode ZP or in Mode MP with an empty chamber)	ppm
H2Oabs	H ₂ O mole fraction in reference cell of analyzer, equal to H ₂ O concentration at inlet of cuvette.	ppm
H2Osam	H ₂ O mole fraction in sample cell of analyzer. Not corrected for dCO2ZP	ppm
dH2OZP	= H2Osam - H2Oabs (in Mode ZP or in Mode MP with an empty chamber)	ppm
Pamb	Ambient barometric pressure	kPa
Flow	Gas flow entering cuvette	μmol/s
Tcuv	Air temperature within cuvette	°C
Tleaf	Leaf temperature	°C
rH	Relative humidity within cuvette	rh %

*ppm= μmol mol⁻¹

4.2 Calculation of CO₂ Mole Fraction in the Chamber – ca

The actual CO₂ concentration within the chamber and around the sample (ca) is measured at the outlet of the chamber (c_o). It is the value measured on the sample side of the analyzer, corrected for dCO₂ZP. dCO₂ZP corrects for the inherent difference between the sample side and the reference side of the analyzer.

$$(1) \quad ca = c_o = CO2_{sam} - dCO2ZP$$

4.3 Modulation of CO₂ Mole Fraction in the Empty Chamber – CO₂buf

Since the Gas Exchange Chamber 3010-GWK1 has a considerable volume, any step change in CO₂ concentration will lead to a slow change in the CO₂ concentration within the chamber, because the inlet concentration will mix with the actual concentration of the chamber. Ideally this mixing will follow an e-function, which in an empty chamber slowly reaches the inlet-concentration CO₂abs.

$$(2) \quad CO2buf_{(t)} = CO2abs_{(t)} + (CO2buf_{(t-\Delta t)} - CO2abs_{(t)}) \cdot e^{-\frac{\Delta t}{\tau}}$$

whereby: $\tau = \frac{EmptyChamberVolume(ml) - SampleVolume(ml)}{0.02242(ml / \mu mol) \cdot Flow(\mu mol / s)}$

Δt : time between measurements (1s)

CO₂buf is the CO₂ mole fraction the chamber would have, if there was no uptake or release of CO₂ by the plant. The name “buf” relates to the word buffer. Previous instruments (CMS400) would have a buffer-vessel in the reference with the same volume as the gas exchange chamber. CO₂buf simulates this vessel.

If for the Empty Chamber Volume, 0 ml is entered, CO₂buf = CO₂abs

If the flow is off, CO₂buf is set to CO₂abs.

If the cuvette is flushed long enough, CO₂buf will become equal to CO₂abs.

4.4 Calculation of the Differential CO₂ Mole Fraction in Measure Mode MP – dCO₂MP

With the Gas Exchange Chamber 3010-GWK1, dCO₂MP is calculated from the CO₂ mole fraction at the outlet of the chamber (ca) and the CO₂ mole fraction CO₂buf, which is calculated from the reference.

$$(3) \quad dCO2MP - dCO2ZP = ca_{(t)} - CO2buf_{(t-CO2delay)}$$

Whereby CO₂delay is the time lag caused by the difference in tube length between the reference side and measuring side of the pneumatics.

With GFS-Win Version 3.15 and higher the CO₂delay is stored in the electronics of Measuring Head, because it is dependent on the tube length of the Measuring Head. The stored standard value is always the value for the flow rate 750 μmol s⁻¹. It will be recalculated for the chosen flow rate. Checking and adjusting the actual CO₂delay is described in chapter 6.1.

If no Measuring Head is connected the CO₂delay can be set with *Option1/AdvancedSettings*.

4.5 Calculation of H₂O Mole Fraction in the Chamber – wa

The H₂O mole fraction in the Chamber (wa) is calculated in the same way as the CO₂ mole fraction (ca). wa is the actual H₂O concentration within the chamber and around the sample (wa) is measured at the outlet of the chamber (w_o).

$$(4) \quad wa = w_o = H2O_{sam} - dH2OZP$$

4.6 Calculation of H2Obuf

H2Obuf is modelled from H2Oabs in the same way as explained for the CO2buf (chapter 3.3 and 4.3).

$$(5) \quad \text{H2Obuf}_{(t)} = \text{H2Oabs}_{(t)} + \left(\text{H2Obuf}_{(t-\Delta t)} - \text{H2Oabs}_{(t)} \right) \cdot e^{-\frac{\Delta t}{\tau}}$$

Whereby τ and Δt are the same values as given in chapter 4.3.

H2Obuf is the H₂O mole fraction that the chamber would have, if there was no uptake or release of H₂O within the chamber.

4.7 Calculation of the Differential H2O₂ Mole Fraction in Measure Mode MP – dH2OMP

With the Gas Exchange Chamber 3010-GWK1, dH2OMP is calculated from the H₂O mole fraction at the exit of the chamber and H2Obuf, which is modelled from the reference.

$$(6) \quad d\text{H2OMP} - d\text{H2OZP} = w_{a(t)} - \text{H2Obuf}_{(t-\text{CO2delay})}$$

Whereby CO2delay is the same value as given above in chapter 4.4.

4.8 Calculation of Transpiration Rate – E,

According to Caemmerer and Farquhar (1981) the transpiration rate is calculated as follows:

$$(7) \quad E = \frac{u_e * (w_o - w_e)}{LA * (1 - w_o)}$$

Whereby:

E = transpiration rate [$\text{mmol m}^{-2} \text{s}^{-1}$],

u_e = molar flow rate at the inlet of the cuvette [$\mu\text{mol s}^{-1}$],

w_o = H₂O mole fraction at the outlet of the cuvette [ppm],

w_e = H₂O mole fraction at the inlet of the cuvette [ppm],
 LA = leaf area [m²].

The terms in equation (7) relate to the values provided by the GFS-3000 as follows:

$$(8) \quad u_e = \text{Flow}$$

$$(9) \quad w_o - w_e = dH2OMP - dH2OZP$$

$$(10) \quad w_o = wa$$

$$(11) \quad LA = \text{Area}$$

Using the values provided by the GFS-3000 and equations (7) -

(11) the transpiration rate E can be calculated as follows:

$$(12) \quad E = \frac{\text{Flow} * (dH2OMP - dH2OZP)}{\text{Area} * (1 - wa)}$$

4.9 Relative Humidity (rh %)

With the Gas Exchange Chamber 3010-GWK1, the relative humidity is not calculated as with the Standard Measuring Head 3010-S, but directly measured within the Chamber.

4.10 Calculation of Vapour Pressure Deficit - VPD

According to Caemmerer and Farquhar (1981) the ALVPD (or VPD) is calculated as follows:

$$(13) \quad VPD = \frac{(w_i - w_a)}{1 - \frac{(w_i + w_a)}{2}}$$

Whereby:

VPD = (Air-to-Leaf-) Vapor-Pressure-Deficit [Pa/kPa],

w_i = H₂O mole fraction within the leaf [ppm],

w_a = H₂O mole fraction in the cuvette [ppm].

w_i is calculated from the temperature of the leaf:

$$(14) \quad w_i = \frac{SVP(Tleaf)}{P_{cuv}}$$

Whereby:

SVP (Tleaf) = saturation vapour pressure at Tleaf calculated according to Goff-Gratch [kPa] (*see* manual of the GFS-3000 chapter 19),

P_{cuv} = total pressure in the cuvette [kPa].

In the GFS-3000 the ambient pressure P_{amb} is measured. Only a small overpressure exists in the cuvette, therefore it is assumed:

$$(15) \quad P_{cuv} = P_{amb}$$

For the Gas Exchange Chamber 3010-GWK1, the H₂O mole fraction in the cuvette w_a corresponds to H₂O mole fraction at the outlet of the cuvette w_o :

$$(16) \quad w_a = w_o$$

Using the values provided by the GFS-3000 and equations (13) - (16) the VPD can be calculated as follows:

$$(17) \quad VPD = \frac{\left(\frac{SVP(Tleaf)}{P_{amb}} - w_a\right)}{\left(\frac{SVP(Tleaf)}{P_{amb}} + w_a\right) + 1}$$

4.11 Calculation of Water Vapor Conductance - GH₂O

According to Caemmerer and Farquhar (1981) the total water vapor conductance GH₂O is calculated as follows:

$$(18) \quad GH_{2O} = \frac{E}{VPD}$$

Whereby

GH₂O = total water vapor conductance [mmol m⁻² s⁻¹],

E = transpiration rate [mmol m⁻² s⁻¹],

VPD = (Air-to-Leaf-)Vapor-Pressure-Deficit [Pa/kPa].

GH₂O can be calculated using the results of equations (12) and (17).

4.12 Calculation of Assimilation Rate - A

According to Caemmerer and Farquhar (1981) the assimilation rate A is calculated as follows:

$$(19) \quad A = \frac{u_e * (c_e - c_o)}{LA} - E * c_o$$

where

A = assimilation rate [μmol m⁻² s⁻¹],

u_e = molar flow rate at the inlet of the cuvette [μmol s⁻¹],

c_o = CO₂ mole fraction at the outlet of the cuvette [ppm],

c_e = CO₂ mole fraction at the inlet of the cuvette [ppm].

LA = leaf area [m²],

E = transpiration rate [mmol m⁻² s⁻¹],

The terms in equation (19) relate to the values provided by the GFS-3000 as follows:

$$(20) \quad u_e = Flow$$

$$(21) \quad c_e - c_o = dCO2ZP - dCO2MP$$

$$(22) \quad c_o = ca$$

$$(23) \quad LA = Area$$

Using the values provided by the GFS-3000, equations (19) - (23) and the result of equation (12), the assimilation rate A can be calculated as follows:

$$(24) \quad A = \frac{Flow * (dCO2ZP - dCO2MP)}{Area} - E * ca$$

4.13 Calculation of Intercellular CO₂ Mole Fraction

According to Caemmerer and Farquhar (1981) the intercellular CO₂ mole fraction c_i is calculated as follows - c_i :

$$(25) \quad c_i = \frac{(GCO2 - \frac{E}{2}) * ca - A}{GCO2 + \frac{E}{2}}$$

Whereby

c_i = intercellular CO₂ mole fraction [ppm],

$GCO2$ = conductance for CO₂ [mmol m⁻² s⁻¹],

E = transpiration rate [mmol m⁻² s⁻¹],

ca = CO₂ mole fraction in the cuvette [ppm],

A = assimilation rate [μmol m⁻² s⁻¹].

The conductance for CO₂ depends on the conductance for H₂O as follows (simplified equation):

$$(26) \quad GCO2 = \frac{GH2O}{1.56}$$

Using the values provided by the GFS-3000, the intercellular CO₂ mole fraction c_i can be calculated as follows:

$$(27) \quad c_i = \frac{\left(\frac{GH2O}{1.56} - \frac{E}{2}\right) * c_a - A}{\frac{GH2O}{1.56} + \frac{E}{2}}$$

Note that the value given for the intercellular CO₂ concentration (c_i) generally has no meaning with closed stomates, since a division by zero or close to zero takes place.

5 Data Handling

5.1 Reading Data into Excel 2003 and higher

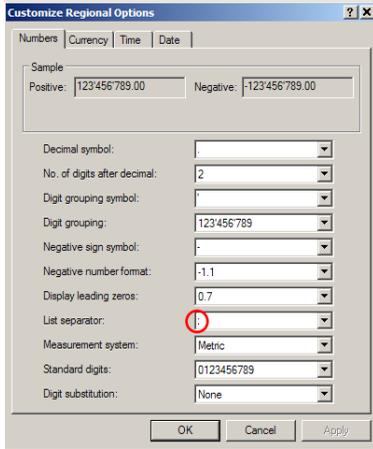


Fig. 12 Customize Reg. Opt.

Language Options/ Customize.

Furthermore, in Excel it might be required to choose the appropriate decimal symbol. This can be done within Excel with: *Extra/ Option/ International/ Decimal Symbol: “.”*

If the general settings for the list separator shall not be changed, and the data all appear in one column, select the first column with the data and then choose: *Data/ Text into Columns/ Delimited/ Other “;” / Next/ Advanced/ Decimal Symbol “.”/ Next/ Finish.*

The data are stored in the character-separated-value format (.csv-format). The character separating the values is a semi-colon. If the symbol used in the character-separated-value format matches the symbol given in Customize Regional Options, then the .csv-file will open up in Excel without problems and data will be automatically separated into columns. If this is not the case, the list separator can be changed with *Start/ Settings/ Control Panel/ Regional and*

5.2 Recalculation of Data

is explained above. The gas exchange data can be recalculated with a new leaf area or a new weight as reference parameter. The button **New leaf area** in the report window (Fig. 13) allows to enter a new leaf area for each object number and to automatically recalculate the data.

The screenshot shows the GFS-Win software interface. The main window is titled "GFS-Win 3.11d (December 2008): DualP4H-GFS.csv". It has a menu bar with "System", "Window", "Option1", "Option2", and "Help". Below the menu bar is an "Info:" field with a "Clear" button. The main area is divided into several sections:

- Settings:** Includes buttons for "Recalc. file", "New leaf area", and "New weight".
- Chart:** A button for "Copy Report".
- Values:** A button for "Font +/-".
- Report:** A large table with columns for various parameters.
- Program:** A button for "Mode MP".

The data table in the Report section has the following columns: dH2O MP ppm, Flow $\mu\text{mol/s}$, Pomb kPa, O2 %, Batt. O2 V, Tcuv °C, Tleaf °C, Ttop °C, rh %, E mmol m^{-2} , VPD Pa/kPa, GH2O mmol m^{-2} , and A $\mu\text{mol m}^{-2}$. The table contains 20 rows of data. To the right of the table, there are summary statistics for CO2abs (699.6 ppm), cj (365.8 ppm), A (10.77 μmol), E (0.45 mmol), GH2O (52.0 mmol), and Tleaf (20.98 °C). At the bottom, there are buttons for "Store MP", "Store ZPcuv", and "Auto ZPirga". The status bar at the bottom right shows "C1: C2.93" and "15:23:34".

Fig. 13 GFS-Win: Window Report

As stated above, for the accuracy of the gas exchange data, it is important to determine an exact zero point for the differential CO_2 and H_2O concentration ($d\text{CO}_2\text{ZP}$ and $d\text{H}_2\text{OZP}$). To get an idea on the zero drift during a measurement, the complete protocol may be repeated with an empty chamber. To recalculate the data with a more exactly determined ZP, the values for $d\text{CO}_2\text{ZP}$ and $d\text{H}_2\text{OZP}$ can be changed within Excel and then recalculated with GFS-Win. To do that the data need to be saved with Excel in the csv-format (character separated value format; use a comma or semicolon as list separator). For the recalculation, press the button **Recalc file** in the Report window.

It is not possible to recalculate the data with another sample volume (see chapter 3.3 and 4.3).

6 Maintenance and Adjustment

6.1 Adjusting CO2 Delay

For the determination of the CO2delay start the procedure *Option2/Calibration/Measuring Head/CO2 Delay*. Write down the actual value and enter “D” to start the determination procedure. A short pulse of CO₂ will be given. In the chart, measure the time lag between the increase in CO₂buf and ca. To do that, the cursor can be changed from an arrow to a cross by pressing the button that is labelled with a cross or arrow (see circle in Fig. 14). Move the cursor over the increase of each curve (see magnified insert in Fig. 14), and calculate the difference of both time-values indicated in the lower left corner of the window chart (see arrow in Fig. 14). After pressing “Next” correct the

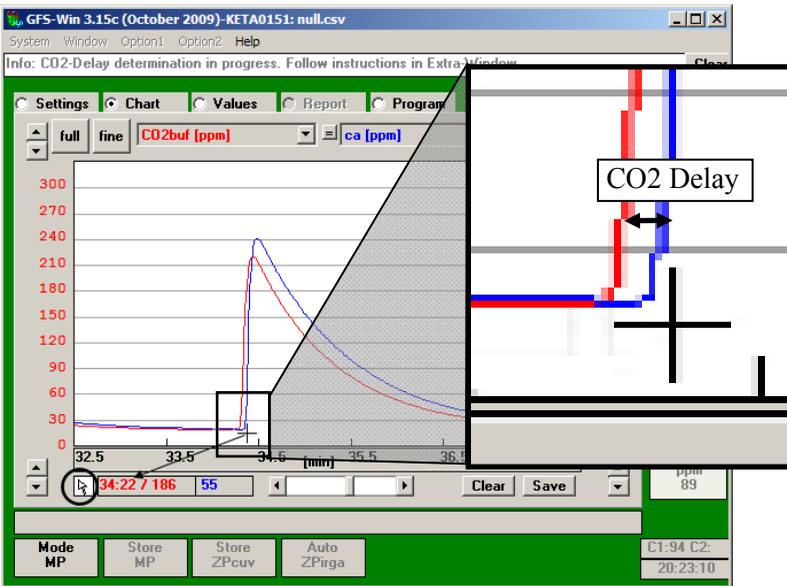


Fig. 14 CO2delay determination

actual value for the CO2delay with the measured time-lag. Repeat the procedure by pressing “Back”, and adjust the value for the CO₂-Delay until the curves both increase in the same moment.

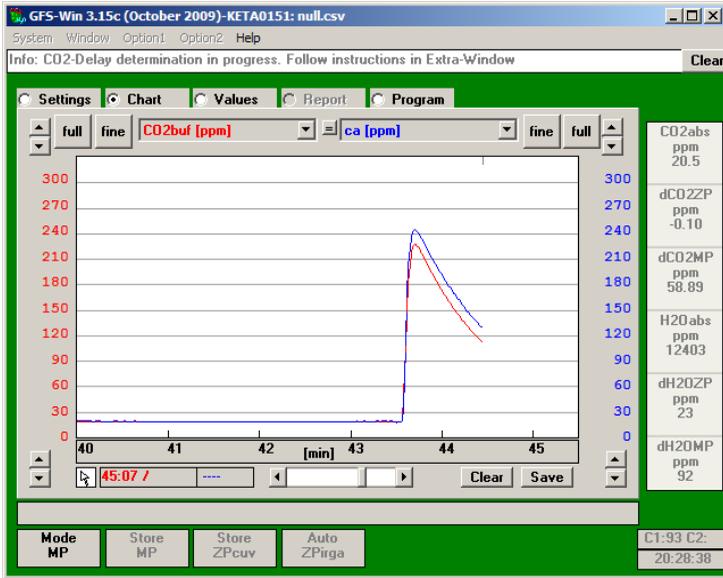


Fig. 15 CO2delay determination with well adjusted value for CO2delay

6.2 Adjusting Empty Chamber Volume

Fig.16 demonstrates the effect of calculating the value CO2buf. It shows the time course of the CO₂ mole fraction within an empty Gas-Exchange Chamber 3010-GWK1 (ca) after a step-change in the inlet CO₂ concentration (CO2abs). It is easiest to do a good step-change by first regulating to a high CO₂ concentration and then, when the CO₂ concentration is reached, not only in the reference (CO2abs) but also in the chamber (ca), switching the CO₂ regulation off. ca now drops with some delay and then adjusts slowly to the inlet CO₂ concentration (CO2abs) as it is mixed in the chamber.

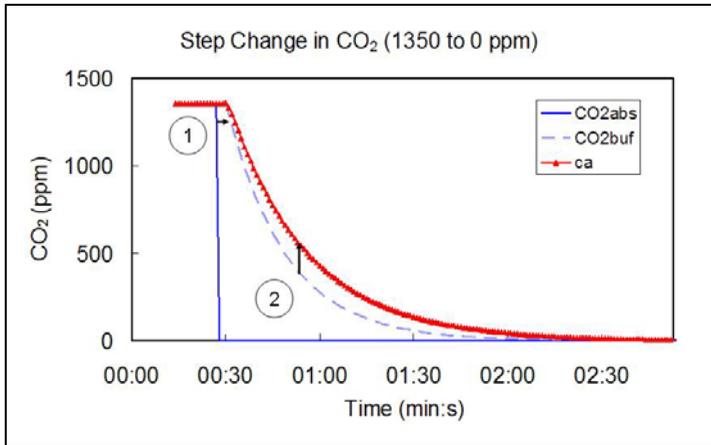


Fig.16 Step change in CO₂ concentration to demonstrate CO₂buf. It shall be modelled so that it matches ca as close as possible with an empty chamber. The difference in the start of the drop (1) is corrected with the CO₂delay (see previous chapter). The difference in the shape (2) is corrected with the setting for the Empty Chamber Volume

CO₂buf is calculated from the reference (CO₂abs) as described in chapter 4.3. Within the electronics of the Measuring Head the value for the volume of the empty chamber is stored (*Option1/ Calibration/ Measuring Head/ Empty Chamber Volume*, Fig. 5), so that CO₂buf matches ca as close as possible, when there is a change in CO₂abs (Fig.16).

6.3 Function Test of Tleaf

The intactness of the thermocouple (measuring Tleaf) should be tested regularly. To test the function of the thermocouple, switch the fan off, place a black piece of paper on Tleaf, and shine some strong light (500-2000 $\mu\text{mol m}^{-2} \text{s}^{-1}$) on it. Tleaf should change its temperature with illumination by several degrees °C. If Tleaf stays constant the thermocouple is broken and needs to be replaced.

6.4 Exchanging the Thermocouple for Tleaf

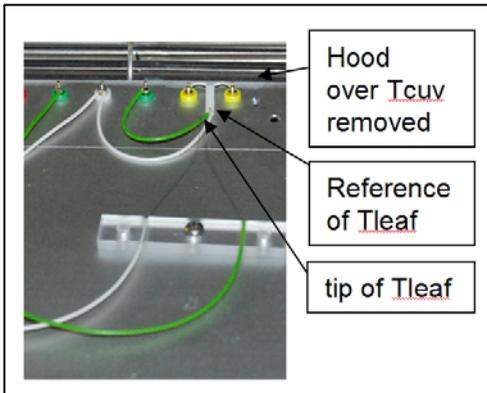


Fig. 17

To exchange the thermocouple, remove the hood covering Tcuv and disconnect the two green, the white, and the two yellow plugs. Connect the plugs of the new thermocouple. Connect the short green wire to the green socket, that is closest to the yellow plugs of Tcuv. Make sure that Tcuv does not

touch the aluminum, but measures the air temperature. After the thermocouple has been exchanged, adjust Tleaf Offset (see next chapter).

6.5 Adjusting Tleaf-Offset

The thermocouple measures the leaf temperature (Tleaf). It consists of two tips, which physically measure the temperature difference between the reference of Tleaf, which is in close contact to Tcuv, and the tip of Tleaf, which should touch the sample. To adjust the zero-offset, there should be no difference between the temperature of the reference (Tcuv) and Tleaf. To achieve that, bring the Tleaf sensor close to Tcuv and close the Gas-Exchange Chamber 3010-GWK1. Press Option1/Calibration/Measuring Head/Tleaf Offset. Wait until Tcuv and Tleaf are in a steady state and then press ok to store the new offset in the Measuring Head.

6.6 Keep Electronics Dry

The chamber is not rain- or spray-water proof.

The electronics of the chamber need to be protected from condensation which might occur with temperature changes. To keep them dry, flush the system with dry air (e.g. compressed air) during the experiment, or exchange the silica gel within the tubes before experiments. This is especially required, when the cooling function of the chamber will be used.

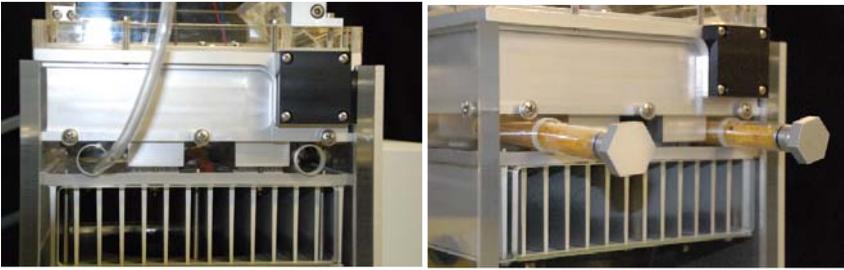


Fig. 18 Silica gel within Gas-Exchange Chamber 3010-GWK1

7 Technical Data

7.1 Gas-Exchange Chamber 3010-GWK1

Design: Chamber consisting of an aluminum cooling block with two pneumatic connectors and transversal fan, flat polymer lid or user-designed cuvette; micro-processor controlled electronics with connectors for temperature sensors, humidity sensor, PAR-sensors, GFS-3000 or 3010-I/GWK connection, power-input; cooled with Peltier-cooling units and ventilator

Measurement of chamber and ambient temperatures: Pt 100 type A, range -10 to 50 °C, accuracy ± 0.1 °C

Leaf temp. measurement: Thermocouple, range: -10 to 50 °C, accuracy ± 0.2 °C

Temperature control: Three modes of temperature control: Constant cuvette temperature, constant leaf temperature, follow ambient temperature with an offset

Temperature control range:

-10°C to 50°C, depending on ambient temperature and radiative heat intake. With 4l volume, dark: 10 K below ambient temperature and 25 K above ambient temperature. With flat lid, dark: 20 K below ambient temperature and 35 K above ambient temperature

Relative humidity sensor: Range: 0 to 100% r.h., accuracy: $\pm 1.5\%$ (5 to 95% r.h.), T_{90} response time (11 to 75% r.h.): <10 s

External miniature quantum sensor: Mini Quantum Sensor MQS-B/GWK1 outside of chamber. Selective PAR measurement, range 0 to 2500 $\mu\text{mol m}^{-2} \text{s}^{-1}$, accuracy $\pm 5\%$, cosine corrected (measuring photosynthetic photon flux density PPFD)

Internal light sensor: Selective PAR measurement, range 0 to 2500 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PAR, accuracy $\pm 10\%$, two sensors, one in the upper and one in the lower part of the cuvette

Cuvette ventilation system: Transversal fan

Maximum sample area: 14 cm x 10 cm

Pneumatic connectors: Hose fittings for 10/8 mm (OD/ID) tubing

Inner volume of the cooling unit alone: 840 ml (up to edge of aluminum frame)

Power supply: AC Power Supply 3020-N for laboratory operation

Power consumption: Max. 45 W

Operating temperature: -5 to 45 °C

Dimension of cooling unit: 26 cm x 25 cm x 19.5 cm (L x W x H)

Weight: 6.9 kg including cables and tubes

Cuvette:

Standard: Flat lid (inside: 16 cm x 14.5 cm, outside: 18.5 cm x 17 cm, volume: 320 ml)

Other design: Available on customer request

7.2 AC Power Supply 3020-N

Design: DC power supply unit for laboratory use

Output voltage: 16 V DC

Output power: 135 W

Mains power supply: 100 to 240 V AC, 50/60 Hz

Operating temperature: 0 to 60 °C

Dimensions: 20 cm x 8 cm x 5 cm (L x W x H)

Weight: 1 kg

7.3 Interface 3010-I/GWK (optional)

Design: USB-RS485 Converter with over voltage protection and connecting cables. For operation of the Gas Exchange Chamber 3010-GWK1 with a PC.

Technical data may change without prior notice

8 Warranty

All products supplied by the Heinz Walz GmbH, Germany, are warranted by Heinz Walz GmbH, Germany to be free from defects in material and workmanship for one (1) year from the shipping date (date on invoice).

The warranty is subject to the following conditions:

1. This warranty applies if the defects are called to the attention of Heinz Walz GmbH, Germany, in writing within one year (1) of the shipping date of the product.
2. This warranty shall not apply to any defects or damage directly or indirectly caused by or resulting from the use of unauthorized replacement parts and/or service performed by unauthorized personnel.
3. This warranty shall not apply to any product supplied by the Heinz Walz GmbH, Germany which has been subjected to misuse, abuse, abnormal use, negligence, alteration or accident.
4. This warranty does not apply to damage caused from improper packaging during shipment or any natural acts of God.
5. This warranty does not apply to underwater cables, connectors, batteries, fiberoptic cables, lamps, gas filters, thermocouples, fuses or calibrations.

To obtain warranty service, please follow the instructions below:

1. The Warranty Registration form must be completed and returned to Heinz Walz GmbH, Germany.
2. The product must be returned to Heinz Walz GmbH, Germany, within 30 days after Heinz Walz GmbH, Germany has received written notice of the defect. Postage, insurance, custom duties,

and/or shipping costs incurred in returning equipment for warranty service are at customer expense.

3. All products being returned for warranty service must be carefully packed and sent freight prepaid.
4. Heinz Walz GmbH, Germany is not responsible or liable, for missing components or damage to the unit caused by handling during shipping. All claims or damage should be directed to the shipping carrier.