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Manual for calibration of Photoacoustic Gas Monitors

Innova 1412 Photoacoustic Field Gas-Monitor
Brüel & Kjær 1302 Photoacoustic Gas-Monitor

Rasmus L. Jensen
Piotr P. Taradajko
Anna D. Chodor



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Indoor Environmental Engineering Research Group

DCE Lecture Notes No. 42

Manual for calibration of Photoacoustic Gas Monitors

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May 2013

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1. Introduction

This manual describes calibration of photoacoustic gas monitors, which are:

- Innova 1412 Photoacoustic Field Gas-Monitor,
- Brüel & Kjær 1302 Photoacoustic Gas-Monitor.

The main description will be based on the former monitor, Innova 1412 Photoacoustic Field Gas-Monitor, which is presented on Figure 1a. The latter monitor, Brüel & Kjær 1302 Photoacoustic Gas-Monitor, see Figure 1b, will be presented in chapter 6 with the explained differences in calibration procedure. The manual is based on *Technical Documentation* (1) and users experience. The manual should be used as a guide line, but in case of any doubts it is advisable to refer to the *Technical Documentation*. In some rarely used cases the procedure is referred directly to Technical Documentation. Some specific or additional procedures will not be explained in the manual, e.g. the manual does not describe the procedure of checking fuses, exchanging filters in the Monitor or setting up the filters. Calibration of Multipoint Sampler and Doser is not considered in this publication. A short description of measurement procedure is presented in chapter 7.



Figure 1. Innova 1412 Photoacoustic Field Gas-Monitor.
(1)

2. Preliminary tasks

In this chapter tasks that should be done before turning on the Monitor, as well the calibration set-up and the Monitor construction are explained.

2.1. Security during calibration

When gas bottles are in the room they are always needed to be safely mounted to a stable place like wall, heavy not movable table etc. The gas bottles should be move with care, they should not fall or be damaged during transportation.

Remember that during measurements or calibration concentration of specific gases e.g. CO₂, N₂O, SF₆ and acetone should not exceed safety limits.

2.2. Checking and replacing the filters

The monitor is equipped with two filtration units, namely internal and external. The paper filters inside the filtration units should be changed at least twice a year, however it is recommended that they are replaced each time before a calibration of the Monitor.

2.2.1. Internal filter

Internal filtration unit is mounted on the air-inlet in the back of the Monitor's panel, see Figure 2. Inside there is a paper filter, which removes small particles, like dust before they reach the measurement chamber of the Monitor. The internal infiltration unit can be easily removed by unscrewing the unit by hand.



Figure 2. Internal filtration unit.

To change the paper filter:

- Make sure that the Monitor is not connected to the power.
- Put rubber gloves on hands and unscrew the internal filtration unit from the air-inlet by turning it anti-clockwise with the fingers.
- Use tweezers to lift the metal ring, see Figure 3.
- Remove old paper filter.
- Using tweezers take a new paper filter from the packaging “Teflon Filter 10 μm ” and holding it by its edge place it inside the filtration unit, see Figure 5a. Be aware not to confuse the filters in the package with the papers which separate them. The filter colour is white and it is not very transparent, while the papers separating the filters are more blue and more transparent. If you are still in doubts you can touch them, the separating paper is more slippery and you can feel some kind of plastic inside. The picture presenting both filter and the separating paper can be found on Figure 4.
- Place the metal ring above the new paper filter, make sure that the ring’s locking tabs fit into the grooves in the unit and gently press the ring, see Figure 5b.
- Place the unit back in the air-inlet of the Monitor and screw it by turning the unit clockwise with fingers.



Figure 3. Lifting the metal ring by a tweezers.

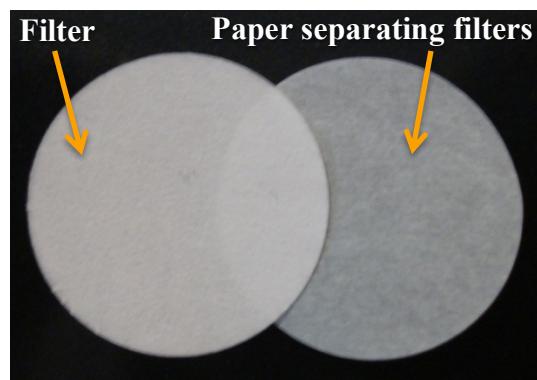


Figure 4. Picture showing filter and the paper separating the filters.



a)

b)

Figure 5. Placing a) new paper filter inside the internal filtration unit and b) the metal ring above new paper filter.

2.2.2. External filter

External air-filtration unit is an optional accessory, however it is recommended that it is always attached to the free end of the air-inlet tubing, e.g. in case of performing environment measurements, see section 3.2. The external unit can be seen on Figure 6. It prevents large particles and insects from being drawn into the unit, while the paper filter inside protects smaller particles from entering the tube.

To change the paper filter in the external air-filtration unit pull the unit off the end of the sampling tube and proceed the same procedure as described in section 2.2.1 for the internal filter.



Figure 6. Picture showing external filter.

2.3. Monitors construction

The measuring principle is based on *Infrared Photo Acoustic Spectroscopy* (PAS) and scheme of the monitor can be seen on Figure 7. The main parts are namely infra-red source, optical filters carousel with six positions, microphone in measuring chamber, pump, air inlet and air outlet. The Monitors base measurements on a precise microphone and because of this the monitors should be placed on stable location during calibration and measurements.

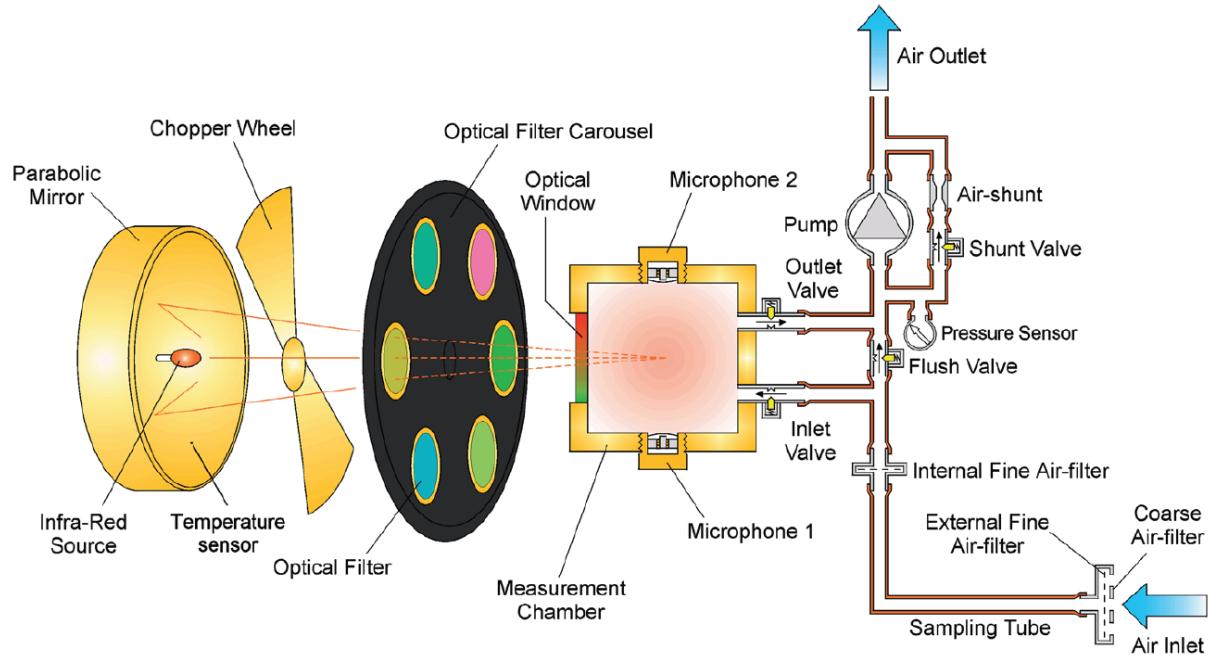


Figure 7. Scheme of the monitor construction. (2)

2.4. Calibration set-up

2.4.1. General calibration set-up

The scheme of general equipment needed to perform the calibration is shown on Figure 8. Three Teflon tubes are connected with each other by a "Y"-piece, exemplary Teflon tubing can be seen on Figure 11. The tube attached to point 1 is connected to the air-inlet of the Monitor, tube connected to point 2 is attached to a gas flow meter and the tube connected to point 3 is attached to the gas cylinder, which is used during the calibration. It is recommended that the Teflon tubing attached to the air-inlet should be maximum 50 m length.

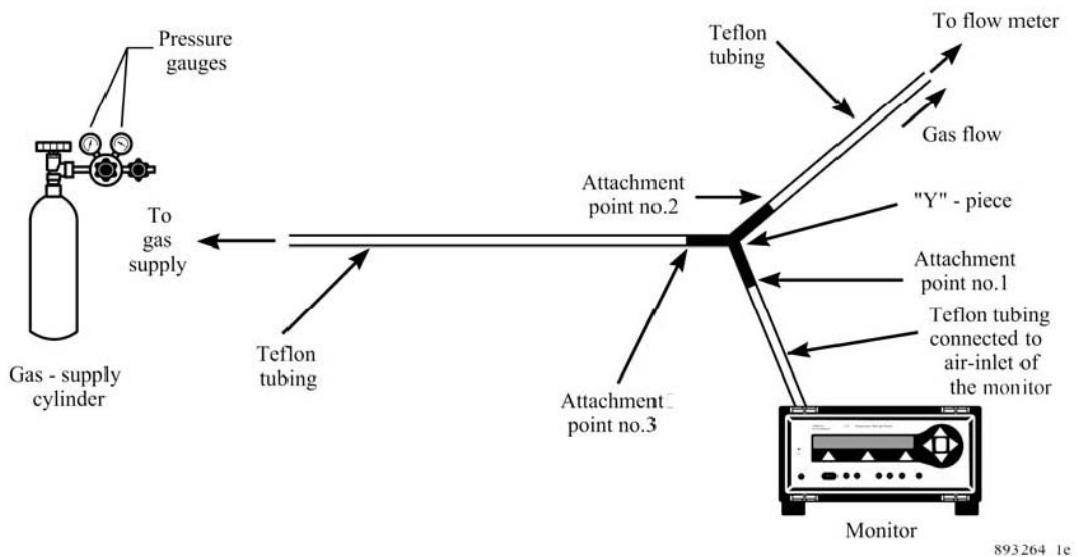


Figure 8. Scheme of general equipment required for a calibration task. (1)

When performing calibration with one of the filters: UA0983, UA0984, UA0985, e.g. carbon dioxide (CO₂), carbon monoxide (CO), dinitrogen oxide (N₂O) additional tubing, called Nafion tubing is required. Picture showing Nafion tubing can be found below, see Figure 9. The Nafion tubing should be connected by tube-fittings to the Teflon tubing between the "Y"-piece and the gas cylinder, see Figure 10 and Figure 11. Do not place it between the "Y"-piece and the Monitor due to higher gas usage.



Figure 9. Nafion tubing.

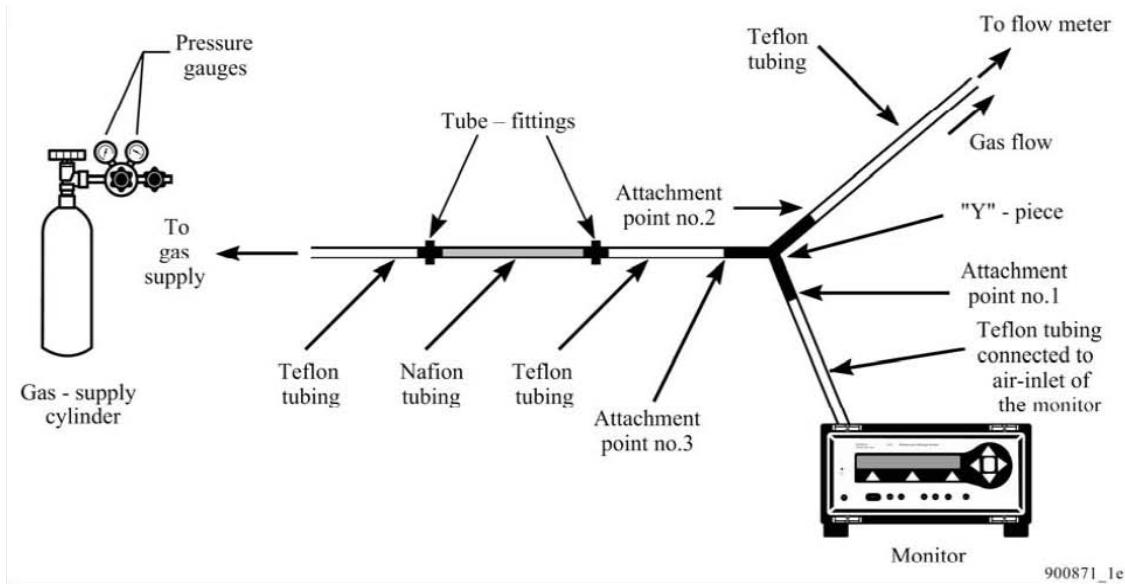


Figure 10. Scheme of equipment required for a calibration task with the Nafion tubing attached. (1)

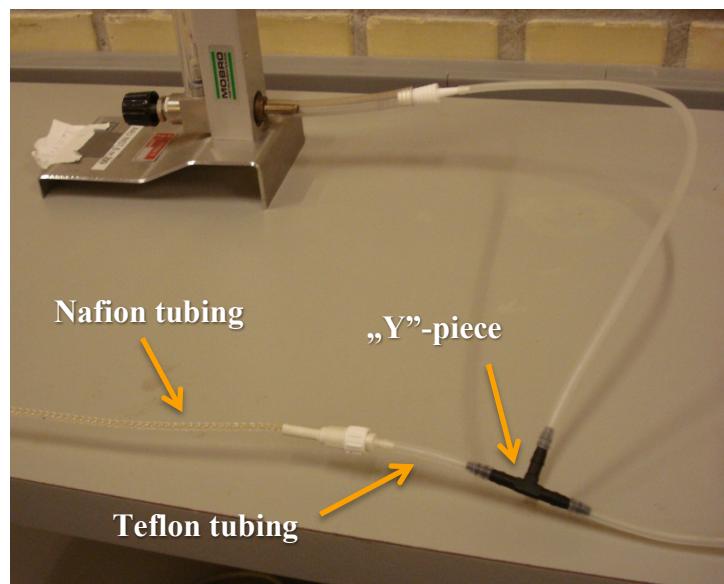


Figure 11. Nafion tubing and “Y”-piece connection.

The flow meter can be seen on Figure 12 and it has two functions in the set-up:

- there should be a net flow out of the Teflon tube attached to the flow meter during the whole calibration procedure and the flow meter allows to check it. When the gas pressure out of the gas cylinder is too low the “flow ball” is seated on the bottom of the flow meter. This can decrease the accuracy of the calibration, because the air can be drawn into the Teflon tubing through the flow meter and dilute the calibration gas.

N.B. The “flow ball” should never be seated on the bottom of the flow meter. It is important to set the flow to the lowest possible value to decrease use of the calibration gas, but also the flow should be observed during calibration especially

when the pump in the Monitor is working. The pump creates under-pressure and it can lower the “flow ball” position.

- it functions as an escape valve, when the pressure in the tubing becomes greater than the atmospheric pressure, the gas flows out through the gas meter. This ensures that the gas entering the analysis cell has always pressure close to the atmospheric one. It is very important that the gas entering the analysis cell has pressure not higher than 0.1 bar above the atmospheric pressure, because of very sensitive microphones inside the monitor. It is never allowed to connect the air-inlet of the monitor directly to the pressure valve of the gas cylinder.

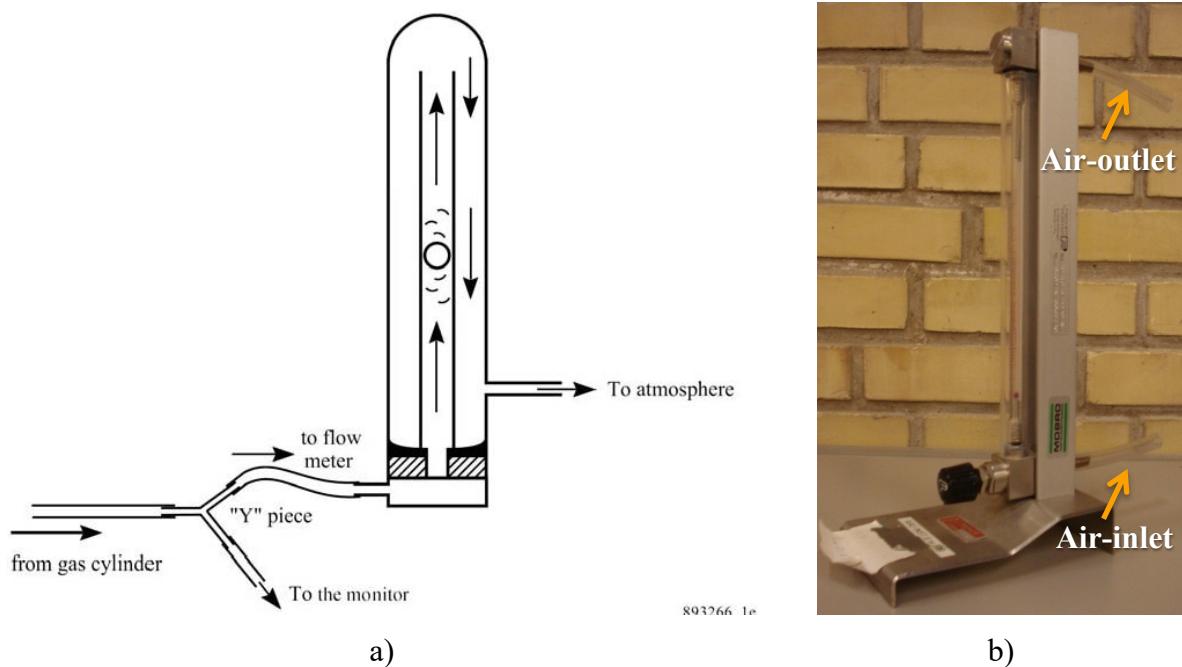


Figure 12. Pictures showing flow meter a) scheme of flow meter's connection b) real flow meter. (1)

The air-outlet tubing of the flow meter should be long enough, so that the sampled gas is carried away to the open air. The same is required from the air-outlet tubing of the Monitor. On Figure 13 can be seen Monitor's back panel with highlighted air-outlet.



Figure 13. Monitor's back panel with highlighted air-outlet.

An exemplary picture of the real calibration set-up can be seen on Figure 14.

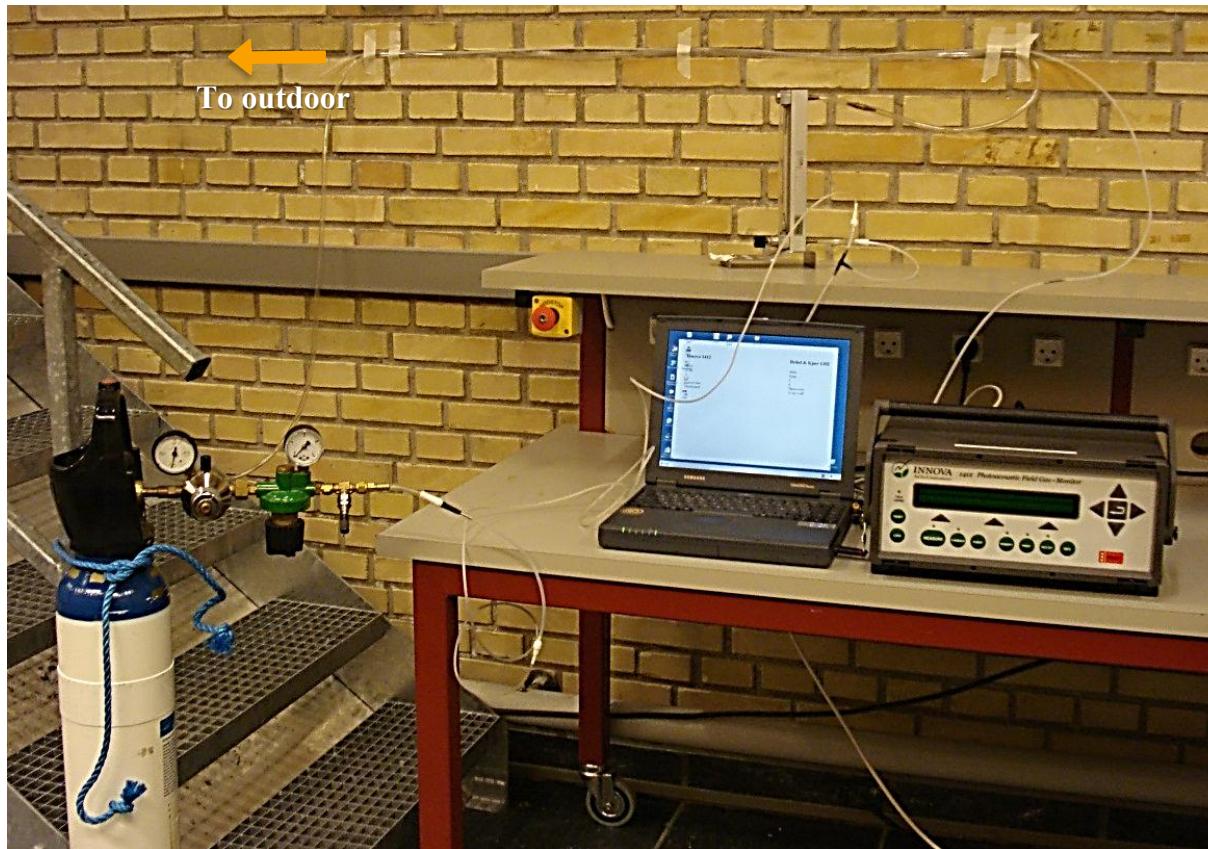


Figure 14. Exemplary calibration set-up.

2.4.2. Calibration set-up for humidity calibration

When performing a humidity calibration clean, wet gas is required. This can be obtained in the way described below.

A zero-gas, e.g. pure nitrogen (N_2) is bubbled through a thermostatically controlled water bath, scheme of the set-up can be seen on Figure 15 and the real set-up is showed on Figure 16. Besides the water bath in the set-up can be seen second empty flask which acts as a safety valve, it prevents from a situation in which the water rises in the water bath and fill in the tubing connected to the "Y"-piece and further flows directly to the analysis cell of the monitor, which may seriously damage the Monitor. The same function as the empty flask can have a separation filter, which is shown on Figure 18. On Figure 16 between the gas supply and the water bath can be seen additional Nafion tubing, however this accessory is not necessary in the humidity calibration and the gas supply and water bath can be connected directly by a Teflon tubing.

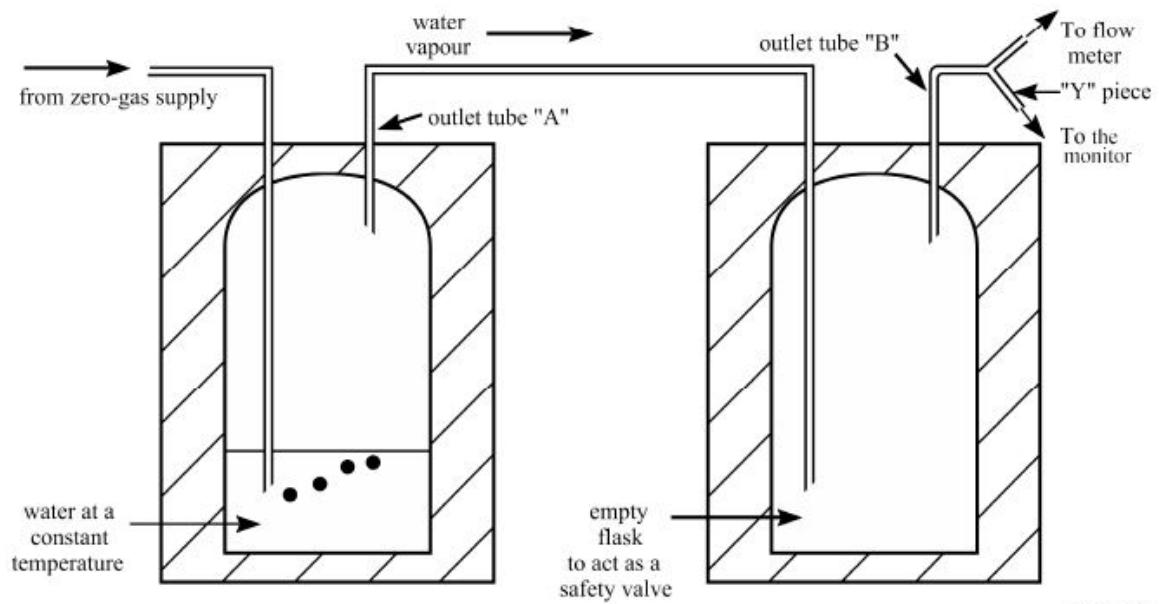


Figure 15. Scheme of obtaining clean, wet gas through a water bath.

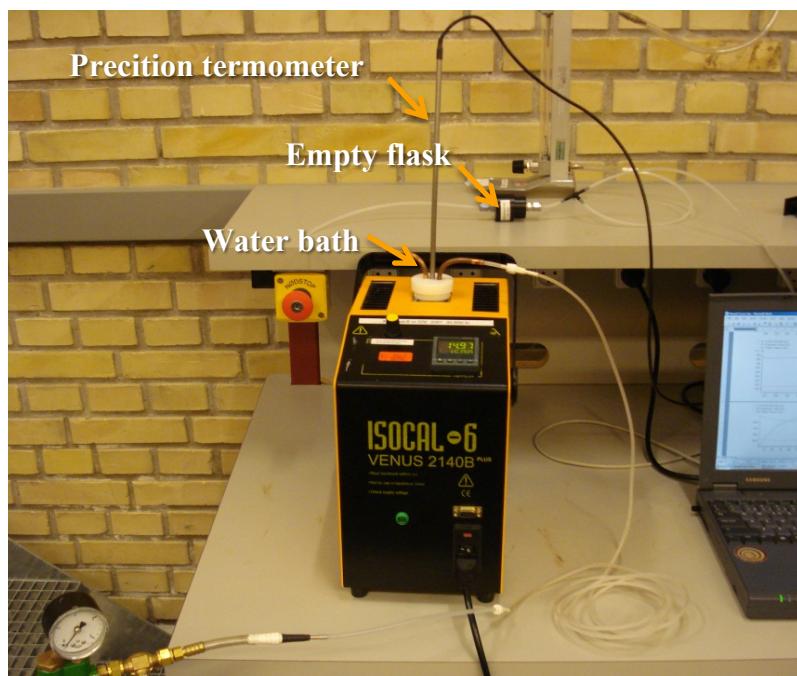


Figure 16. Set-up for humidity calibration.

Following steps should be performed to obtain a humidity calibration set-up:

- A special water bath, see Figure 17a, is filled with demineralised water. There should be enough water inside the bath, so that the bath's inlet tube is covered by water, but the outlet tube is above the water level. The distance between outlet and water should be large enough not to suck water from generated bubbles.
- The water bath is carefully placed into an ISOCAL 6 equipment and the Teflon tubing is connected to inlet and outlet of the water bath, see Figure 17b.
- The separation filter shown on Figure 18a, which functions as an empty flask, is mounted between the water bath and the "Y"-piece, see Figure 18b.

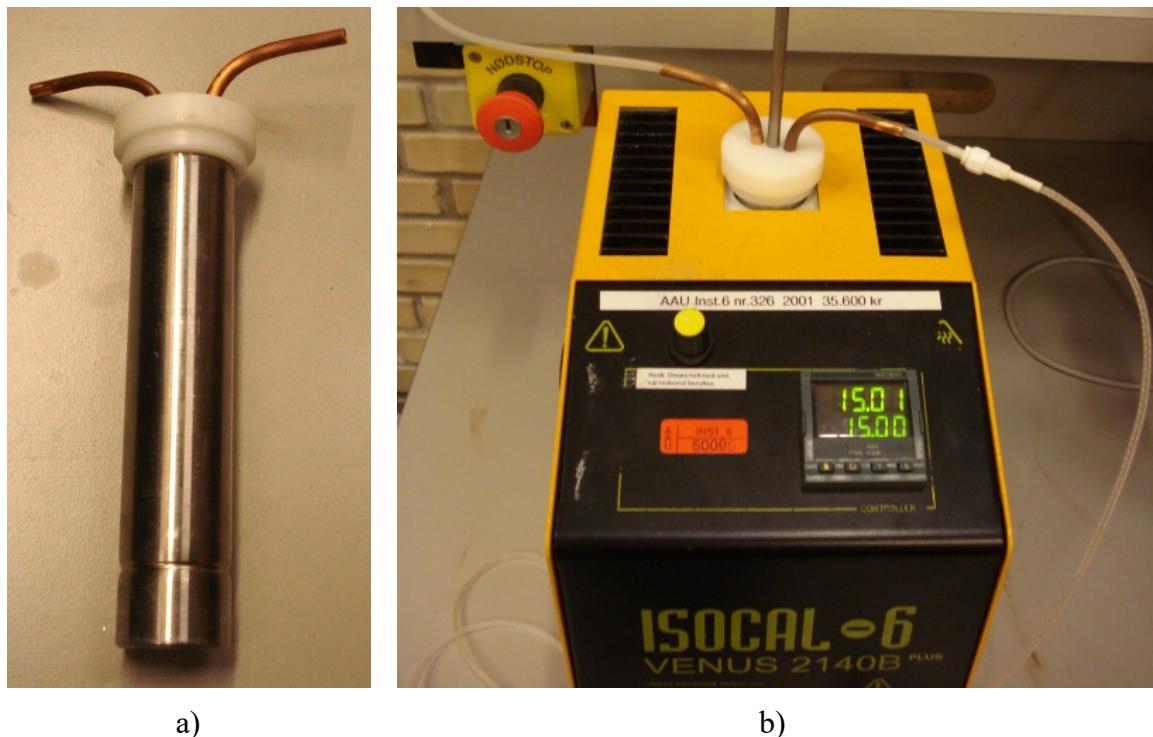
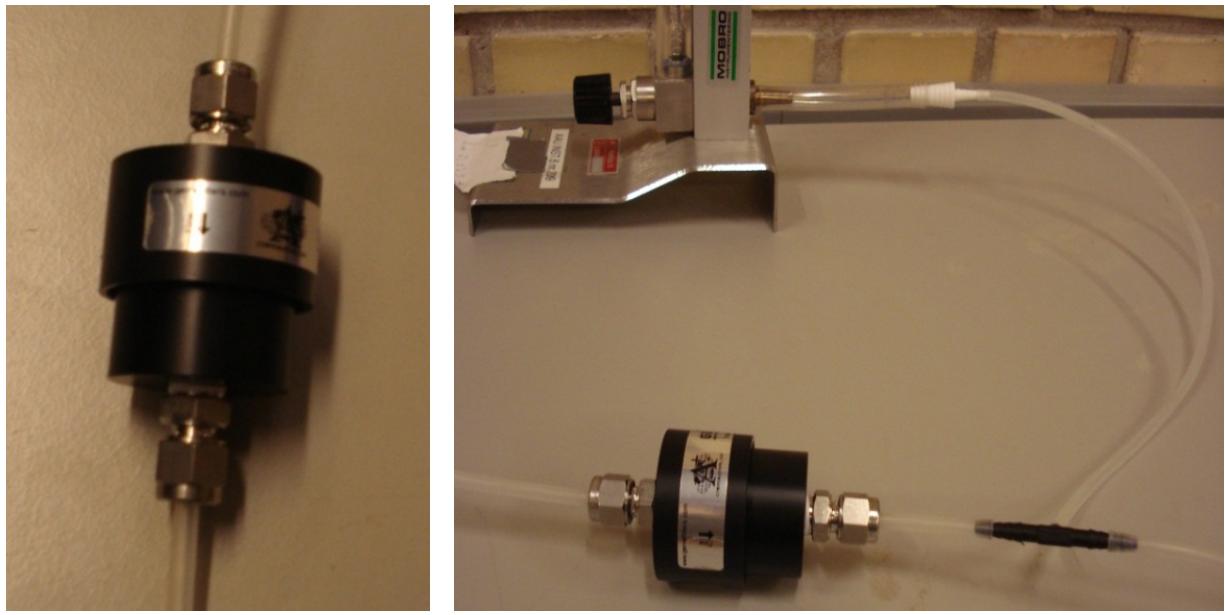


Figure 17. Pictures of a) water bath and b) water bath with precision thermometer placed into ISOCAL 6 and connected with Teflon tubing.



a)

b)

Figure 18. Pictures showing a) The, functioning as an empty flask, b) connection of the separation filter as “empty flask” to a Teflon tubing.

It should be noted that it is very important to obtain water vapour, which concentration is below the saturated water-vapour pressure of the ambient air. In other case the water vapour can condense in the analysis cell. In practice it means that:

- The Monitor must have time to be warmed up or reach the ambient temperature of the room, before the calibration is started.
- The temperature of the water bath must be at least 2°C below the ambient temperature (for example if the ambient temperature is 20°C, the temperature of the water bath can be maximum 18°C). For most of the cases water temperature of 15°C set in *ISOCAL 6* is low enough and exemplary calculations of water concentration, which has to be typed in the software during calibration, are shown in section 4.3. The temperature used in calculations should be measured by precision thermometer.

3. Tasks before calibration

Before starting the calibration it is advised to perform the necessary preliminary tasks, see chapter 1. The computer with installed *Gas Monitoring Software 7304* for the Monitor should be turned on. After Windows started up the Monitor can be turn on at the mains. It should also be noted that the Monitor should be keep for some time in room temperature before starting if it was brought from cold environment.

A problem with power supply for the Monitor might mean that the fuses in the monitor are broken. For checking or changing the fuses in the Monitor it is advisable to follow section 2.3 *Checking /changing the Fuses in the Monitor* in *Technical Documentation* (1).

3.1. Starting the software for the monitor

When the Monitor is ready to use the software can be opened. It should be possible to find the icon on the desktop of the computer, see Figure 19a, as well as the connection information for *Innova 1412* and *Brüel & Kjær 1302 Gas Monitors* presented on Figure 19b and Figure 19c respectively.

	Innova 1412	Brüel & Kjær 1302
9600	9600	9600
Even	None	
1	2	
7	8	
Leased line	Three-wire	
Hardwired	X-on/x-off	

a)

b)

c)

Figure 19. Pictures of a) software's icon for calibration and communication configuration for b) Innova 1412 and c) Brüel & Kjær 1302 Gas Monitors located on the desktop of the computer.

- Start the Calibration Software. The window *Communication* should appear, see Figure 20a.
- Select the correct port, which is used to communicate with the Monitor (usually COM1), and check that the communication parameters are consistent with the ones presented on Figure 19b and click OK.
- Select *New Calibration Task*  (*Task → New*) and type in the description of the calibration task, see Figure 20b, and click OK. If you want to use an existing task then click on *Open*  (*Task → Open*), highlight the desired name and click OK.
- A new window should appear, which means that file is ready to be used for calibration, see Figure 21a.

- It is advised to check units which the monitor is using before starting calibration. The units can be found in Task menu. Pull down the *Task* menu, click on *Units* (*Task* → *Units*) and examine the Units dialogue that is displayed, see Figure 21b. The monitor measures raw data (μV), so these units do not affect the display data for the calibration (μV), but for example input values.

N.B. It is advisable to set the gas concentration unit to the same that manufacturer uses on gas bottles. Often it is parts per million (ppm). Also it can be useful to set water vapour concentration to absolute humidity (mg/m^3). As a result no additional recalculation will be needed.

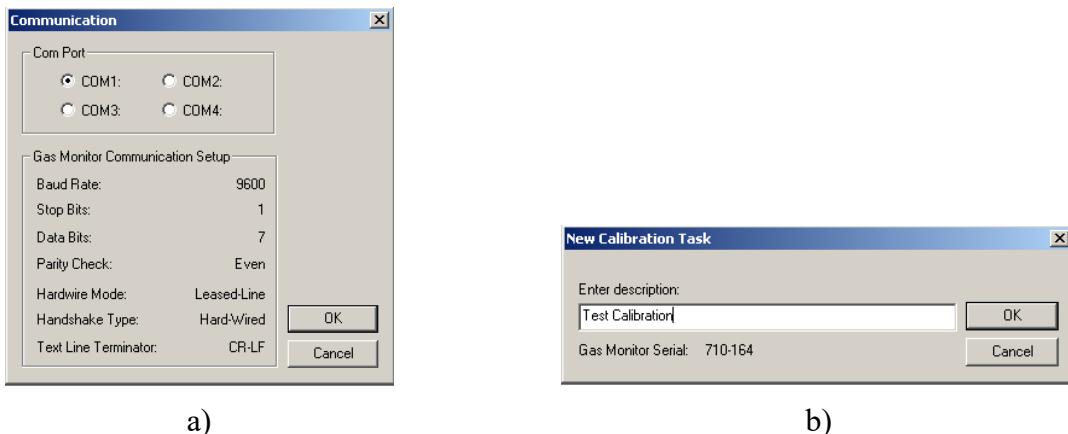


Figure 20. Software dialogue for a) communication and b) task description.

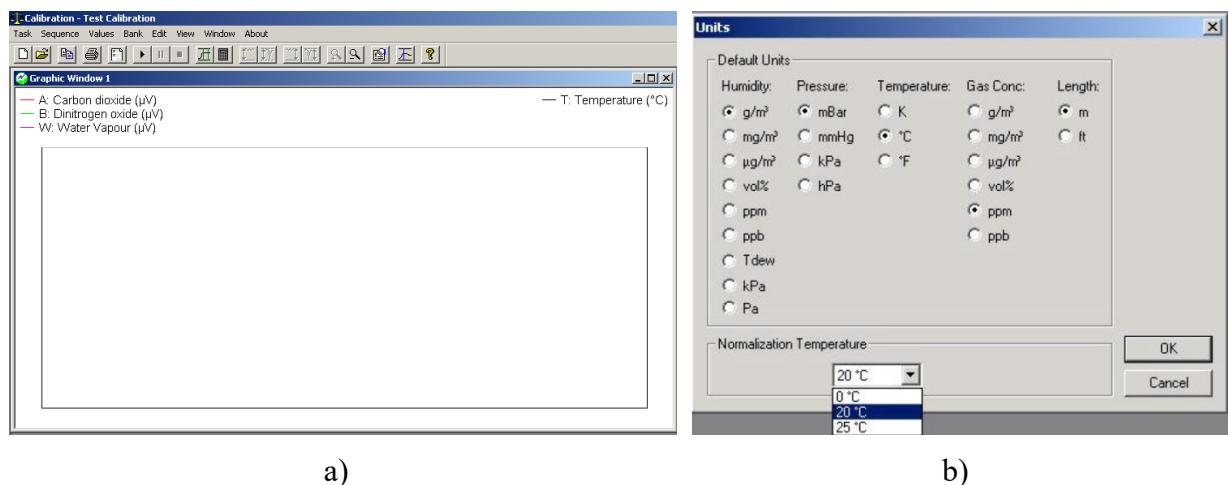


Figure 21. Picture of software's dialogues: a) starting dialogue – window appearing before starting calibration and b) units dialogue.

3.2. Warming up the Monitor

Before starting the calibration task it is advisable to warm up the Monitor to decrease measurement time and gas usage. In the Monitor it is possible to set-up Continuous Warm System to ensure that the Monitor is kept warm, when the monitor is not measuring. The function becomes active after Partial Reset, Power up or stop of Measurement. The Monitor can be set-up also by using its front panel, which can be seen on Figure 22. In practise it means that you need to proceed:

- Click *Set-Up* button on the front panel and select *Configuration*, next *System*, later *General* and *Tests* settings (*Set-Up* → *S3* → *S1* → *S1*).
- Find *Continuous Warm System* using arrows on the front panel (▼ → ▼ → ▼) and click *Yes* (*S3*).
- The warming up will start after Partial Reset, Power up or stop of Measurement. Partial Reset can be selected in Reset menu from the front panel (*Reset* → *S2*).

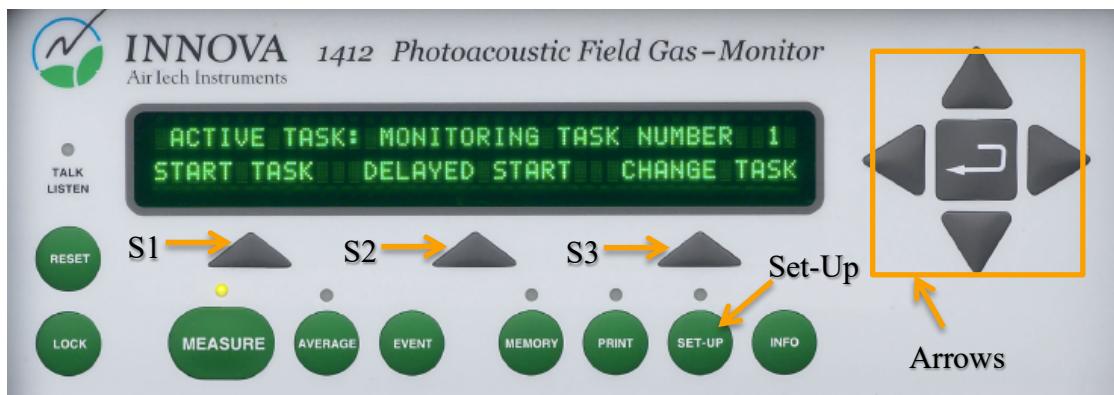


Figure 22. Front panel of the Monitor.

Another possibility to start warming up is by setting an environment measurement. In this case the temperature of the Monitor can be observed. The inlet to the monitor instead of connecting to the gas supply should be left in the laboratory. The free end of the sampling tube should be attached to external filter, see section 2.2.2 *External filter*.

- Prepare the software for the calibration, see section 3.1 *Starting the software for the monitor*. Warming up the Monitor can be conducted in separate file so it will not confuse user during calibration procedure.
- Pull down the *Sequence* menu and select *Settings* (*Sequence* → *Settings*).
- In *Calibration* index card select *Zero Point Calibration (All filters)*, see Figure 23a.
- In *Gas* index card click *Reload Filter Info*, see Figure 23b. This can take a moment, so wait until it has finished before continuing.

- In *Sampling* index card select *Fixed Time Flushing* and choose flushing times, which can be 8 s for chamber and 3 s for tube, see Figure 23c. Click OK.
- *Start* measurements ▶ (or *Sequence* → *Start*) and wait until the temperature will reach around 40-45 °C, see Figure 24.
- *Stop* the measurements □ (or *Sequence* → *Stop*) and prepare next step of the measurements. In case of temperature drop in the Monitor repeat warming up due to temperature decrease of the Monitor.

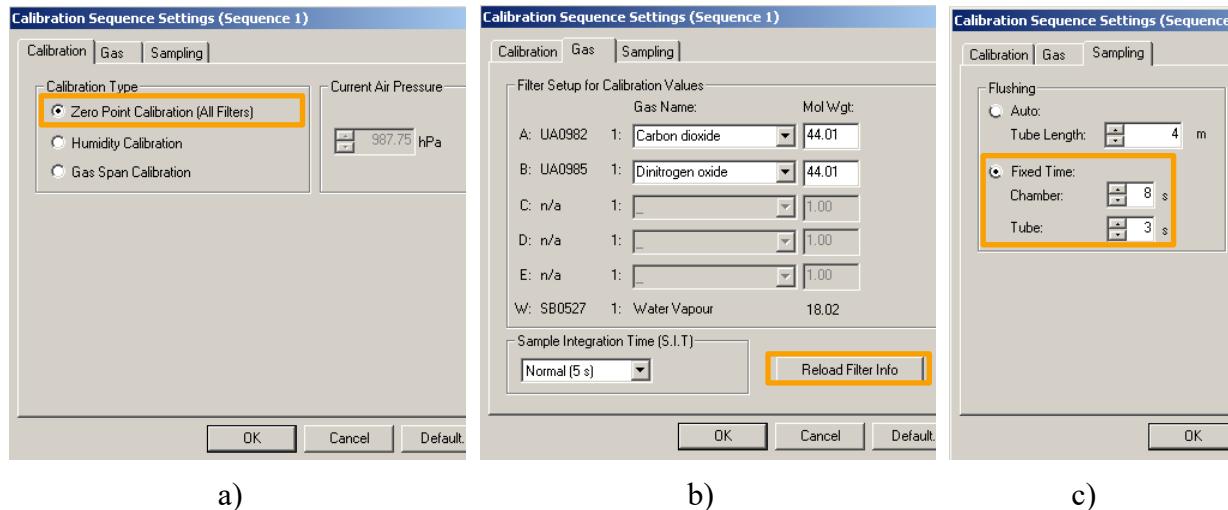


Figure 23. Sequence Settings index cards for a) Calibration, b) Gas and c) Sampling.

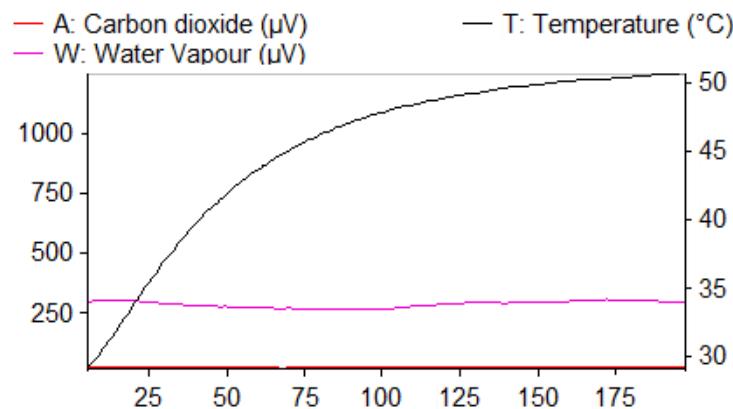


Figure 24. Data for the measurements during warming up the Monitor

4. Calibration

For a new calibration procedure it is advisable to create a new file, which will be used for the whole process of calibration and for all the gases. Setting-up the new file is described in section 3.1 *Starting the software for the monitor*.

The calibration should be proceeded after the Monitor is warmed up. Warming up the Monitor is described in section 3.2 *Warming up the Monitor*. Procedure of calibration can be seen on Figure 25 presenting simplified algorithm.

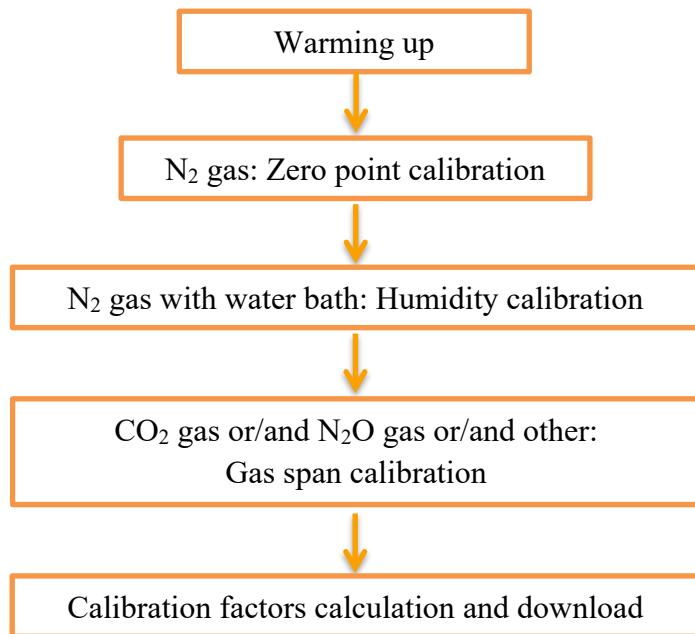


Figure 25. Simplified calibration algorithm.

4.1. Calibration Factors

The Monitor is using Calibration Factors to calculate concentration of specific gases in the gases mixture. The calculation of gas concentration based on linear curve approximation is presented on Figure 26. The zero-point calibration is needed to find offset point for the calculation (point A on the figure). The span calibration for different gases and water vapour (point B on the figure) is needed to find the angle of the span calibration line, which is expressed by span calibration conversion factor.

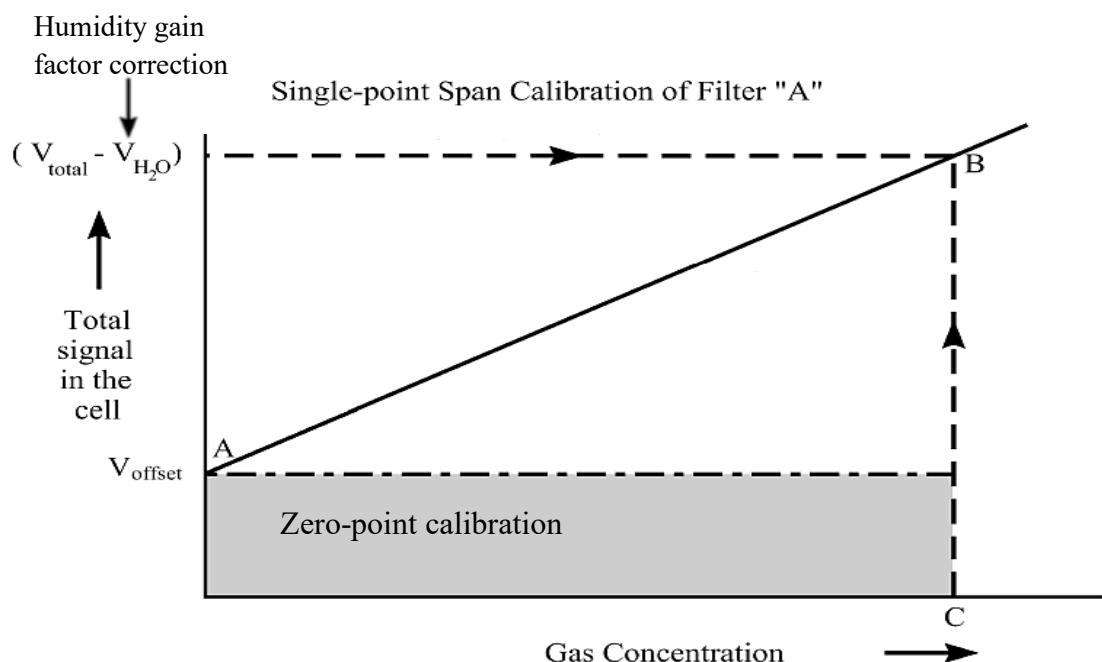


Figure 26. Graph showing gas concentration calculation. (1)

It should be noted that for each filter there are five banks available. Banks are memory location for calibration factors. Default location of the calibration is bank number 1, but the other banks can be used for instance when one filter is used for measuring two gases, so bank number 2 will carry the information about second gas.

Each of the calibration is made for specific gas for the selected filter. There are five slots for filters, named from A to E, and additional for water vapour, named W. Filters have different properties and can be used only for specific gases, see *Poster: Gas Detection Limits* (3). According to *Technical Review* (4), when selecting one optical filter for monitoring a single gas, the following should be considered:

- The detection limit or, alternatively, the sensitivity factor,
- Interference from atmospheric water vapour and carbon dioxide,
- Interference from other gases likely to be present in the monitoring environment, including some common trace gases.

Due to interference of the water vapour on all the filters and appearance in the measuring conditions the correction for the water vapour is needed. The correction is made by humidity gain factor and it should be calculated for all the filters. The correction for the cross-interference is needed, if in the measured sample except measured gas there is another gas that meets one of the two conditions:

- Other gas has high influence on the filter that is used. This means that a large part of the signal will be affected by the interference, which will decrease accuracy and change the result.
- Other gas has small influence on the filter that is used, but the amount of the gas in the sample can change. This means that the accuracy of the measurement will be strongly affected and the result can be incorrect.

So the filter can be used for the chosen gas without cross-interference calibration only, when other gases in the samples have small or preferable no influence on the signal and have stable concentration. In other case the same correction as for the water vapour should be made if the result on one filter can be affected by other gases. Cross-interference calibration factor purpose is to correct the result for influence of other measured gases.

Installed filters type and their location as well as an exemplary gas that they can measure and the gases cross interference on the other filters can be seen in Table 1. Additional information about possible gases that can be measured can be found in *Poster: Gas Detection Limits (3)*. Cross interference information can be found in actual *Service Report*.

Table 1. Filters type and their location with exemplary gas that they can measure and the gases cross interference on the other filters.

Filter (location, type)	Gas (name, molecular)	Installed? *		Cross interference on other filters? *			
		Innova 1412	B. & K. 1302	A	B	C	D
A UA0985	Dinitrogen oxide, N ₂ O	+	+		-	+	+
B UA0982	Carbon dioxide, CO ₂	+	+	+		-	+
C UA0970	Aceton, C ₃ H ₆ O	-	+	+	+		+
D UA0988	Sulphur Hexaflouride, SF ₆	-	+	+	-	+	
E	empty	-	-	-	-	-	-
W	Water vapour, H ₂ O	+	+	+	+	+	+

*) Plus (+) means "yes" and minus (-) means "no".

4.2. General settings

In this section steps which are common in different calibration types will be explained. The calibration should be proceeded only when the correct set-up is prepared.

- Pull down the *Sequence* menu and select *Settings* (*Sequence* → *Settings*)
- In *Calibration* index card click on the radio-button to select the desired calibration type. The individual sections below explain details about different calibration type. The exemplary *Calibration* index card can be seen in Figure 23a.
- In *Gas* index card click *Reload Filter Info* if you have not uploaded it before. This can take a moment, so wait until it has finished before continuing. Check the filter, gas names and molecular weight information. If you are only recalibrating the Monitor for the same filter positions and memory banks, then the names of the gases will be probably correct.

If you are calibrating a new gas or an existing gas in a new filter bank, then the name of the gas and the molecular weight need to be typed in. This can be done in the *Gas* card and details are described in *Technical Documentation* (1) in section *14.11.1 Setting-up a Span Calibration- PC Use*. Before changing these information contact person responsible for the Monitor. More information about filter banks can be found in *Technical Documentation* (1) in section *14.6.1 Retaining Existing Calibration Factors*.

Click in the *Sample Integration Time* (S.I.T.) field, and select the desired time. For standard usage Normal (5 s) time is enough.

N.B. The S.I.T. value should be set to the same as those which are planned to be used later for monitoring. Higher S.I.T. increases precision and measuring time, see e.g. *Poster: Gas Detection Limits* (2).

- In *Sampling* index card select the desired Flushing Type.
- N.B.** the *Flushing* type and values should be set to the same as those used when monitoring
- Select *Fixed Time Flushing* and choose flushing times, which can be for instance 8 s for chamber and 3 s for tube, see Figure 23c. Click *OK*.
- After these steps the settings for calibration should be prepared and the calibration measurements can be started. To start the measurements click *Start* measurements  (or *Sequence* → *Start*). The measurements should continue until the results are stable.
- Stop the measurements  (or *Sequence* → *Stop*).

The calibration should be repeated for all the gases and the next step for calculation of coefficients is described in chapter 5 *Calibration Factors Calculation*.

4.3. Zero point (N_2)

In the zero-point calibration for all the filters zero-gas is supplied for instance pure nitrogen (~100% N_2). The set-up and procedure is described in preceding section. The zero-point calibration should always be performed for all the filters.

N.B. The zero point calibration requires humidity gain factors stored for the filters that are going to be calibrated.

This means that:

- a) If you have already stored humidity gain factors for the filters:
 - You can use them when performing zero point calibration.
 - Or you can perform humidity-interference calibration in *Humidity Calibration*, see Figure 27, in the same Calibration Task. A new humidity gain factors can be calculated at the end of calibration, which is explained in section 5.2 *Calculating and downloading*.
- b) If the humidity gain factors are not stored for the filters from previous calibrations, e.g. the filters are going to be used for the first time:
 - You have to perform humidity-interference calibration in *Humidity*, see Figure 27, in the same Calibration Task. The humidity-interference can be performed together with water-vapour span calibration. A new humidity gain factors can be calculated at the end of calibration, which is explained in section 5.2 *Calculating and downloading*.

4.4. Humidity calibration (H_2O)

The gas supply required during the humidity calibration is a clean, wet gas supply, the set-up and the procedure of obtaining the gas is described in section 2.4.2 *Calibration set-up for humidity calibration*.

The water-vapour filter has two different functions:

- The most important function is to enable any other signal to be compensated for the water-vapour interference.
- Its second function is to measure absolute water-vapour concentration in the samples. To be able to do this, the filter has to be additionally span calibrated.

When the Humidity Calibration button is selected, see section 4.2 *General settings*, two check boxes will appear in the *Calibration Parameters* field, see Figure 27. The button *Perform Water Vapour Span Calibration* needs to be selected if the absolute water-vapour concentration in the samples needs to be measured. In this case it is necessary to enter the water concentration in the gas which is used, details of the water concentration calculations are explained in section 4.4.1 *Water concentration calculation*. Button *Humidity Interference*

Calibration needs to be selected both if we want to perform water-vapour interference compensation. Although interference calibration is performed on all of the filters, it is possible to choose, which filters will receive the humidity gain factor, when the calibration factors are calculated and downloaded, see section 5.2 *Calculating and downloading*.

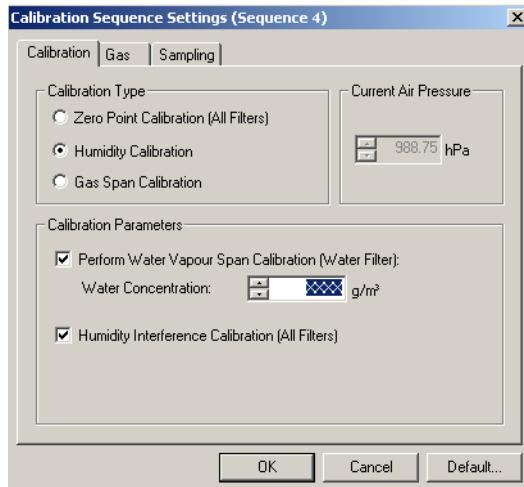


Figure 27. Sequence Settings index cards for Humidity Calibration.

4.4.1. Water concentration calculation

The water vapour should be calculated for temperature of the water bath. Calculation of vapour amount in the gas can be found in Excel spread sheet *Water Vapour Calculation.xlsx*. Exemplary calculation formulas for absolute humidity and vapour pressure are presented below in equation 1 and 2, respectively. The equations are based on (5) and (6).

$$AH = 2.167 \frac{p_{H_2O}}{t} \quad (\text{eq. 1})$$

$$p_{H_2O} = 610 \cdot 10^{\frac{7.45t}{253+t}} \quad (\text{eq. 2})$$

AH	Absolute humidity [g/m ³]
p_{H_2O}	Vapour pressure [Pa]
t	Temperature of water bath [°C]

4.5. Gas span calibration

During the span calibration a supply of particular gas (here CO₂ and N₂O used as an example) of known concentration is attached to the air-inlet of the Monitor. Before the span calibration, the zero-point and humidity-interference calibrations of the filter must be performed. For the span calibration the signal is measured using the filter, which is being calibrated and the water-vapour filter, which means that the total signal of the calibrated filter can be later compensated for any signal produced by water-vapour's absorption of light.

The span calibration can be performed in two ways depending on how linear is the relationship between gas's concentration and a signal it produces :

- Normal precision: *One-Point Calibration* — should be used, when the measurements are within the linear range. In practice for the most common gases, the linear range is between the gas's detection limit and up to 10 000 times the detection limit,
- Special precision: *Two-Point Calibration* — should be used in the non-linear range and when the measurements are over a dynamic range of 100 000, which means that the maximum measured value is 100 000 larger than the smallest. More details about determining the linearity can be found in *Technical Documentation* (1) in section *14.11 Span Calibration*.

In this manual only the one-point calibration is described as it is the most common one. When a one-point calibration is performed the concentration of span gas should be at least 100 times its detection limit and preferably not higher than the highest concentration which is supposed to be measured. The detection limit for example for CO₂ is equal to 1.5 ppm and for N₂O is 0.03 ppm. An exemplary values for concentration range and calibration gas can be found in Table 2.

Table 2. Exemplary concentration range and details for CO₂ and N₂O

Gas name	Detection limits [ppm]	One-Point Calibration measuring range [ppm]	Calibration gas concentration	
			[ppm]	[-]
CO ₂	1.5	1.5 to ~15000	≥ 150	75% - 100% of the highest concentration expected to measure
N ₂ O	0.03	0.03 to ~300	≥ 3	

4.5.1. Cross-interference calibration

If any measured gas is absorbed by more than one of the installed optical filters, then it is advised to perform the cross-interference calibration. This provides the information, how large is the signal that is caused by other calibrated gases, and subtracts it from the result. This gives the real concentration not affected by interfering gases. The details about interference of different gases can be found in *Poster: Gas Detection Limits*, (2) or (3). In this way during the span calibration the signal is measured not only by the filter, which is being span calibrated and the water-vapour filter, but also by the other installed optical filters. Cross-interference calibration decreases the effect of other gases concentration or variation for the gas measurements on selected optical filter. It should be noted that the cross-interference calibration cannot be performed alone and always has to be followed by the span calibration.

4.5.2. Setting-up the span calibration

When the *Gas Span Calibration* button is selected, see section 4.2 *General settings*, the *Calibration Parameters* field will appear as shown on Figure 28.

If you perform a single-point calibration, then make sure that the *Perform Two-Point Calibration* button is not selected, enter the concentration of gas that will be measured and if the cross-interference calibration is necessary, then select the button *Perform Cross Interference Calibration*. If you want to perform two-point calibration, then look at the details in *Technical Documentation (1)* in section 14.11.1 *Setting-up a Span Calibration- PC Use*.

N.B. The span calibration has to be performed for each filter individually, therefore this procedure has to be repeated for each gas that you want to calibrate.

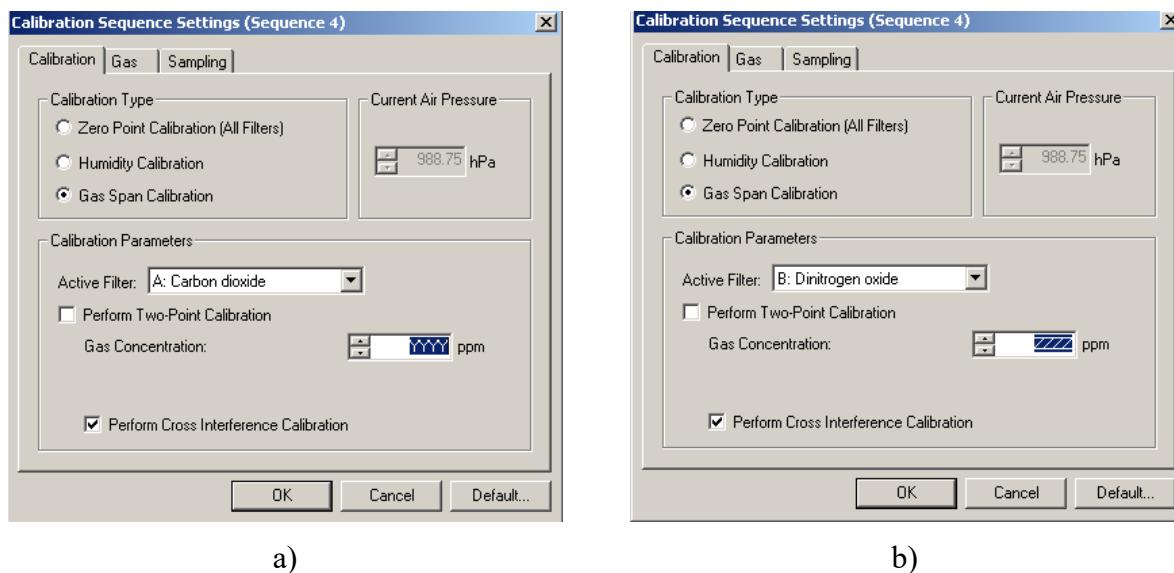


Figure 28. Gas span calibration Sequence Settings: Calibration Parameters a) CO₂ b) N₂O.

5. Calibration Factors Calculation

After all the measurements for calibration are finished the spans for stable results can be selected and calibration factors can be calculated.

5.1. Span selection

After the Calibration Task is finished the spans of stable results can be found. If there is more than one calibration done in the Task the graph can be cut for the better view of specified time:

- Pull down the *Edit* menu and click on graph *Window Properties*  (or *Edit* → *Window Properties*)
- In *Interval* index card in *Measurement Sequence* box select specific interval, see Figure 29a, where *Sequence 1* means first measurement done between Start and Stop in the whole Calibration Task for instance warming up. Click *OK* and the specified interval will be selected.
- To choose span for stable results in *Window* menu click *Cursor Values*  and click on the graph and select result span for stable conditions (*Window* → *Cursor Values*). Mean, minimum, maximum and standard deviation values are presented in *Cursor Values* dialogue, see Figure 29b, and can be used to locate suitable range of data.
- To select span for stable results in the *Sequence* menu click *Mark Interval*  (*Sequence* → *Mark Interval*). An exemplary graph window with selected interval can be seen on Figure 30a.
- All the calibration intervals for calibration factors calculation should be selected and an exemplary final graph can be seen on Figure 30b.

The shortcuts used on the graph represent:

- ZP is zero-point calibration
- HS is humidity span calibration
- HI is humidity interference calibration
- HIS is humidity interference and span calibration
- SHA is a Single point or Span calibration for filter A (SHB is for filter B etc.)

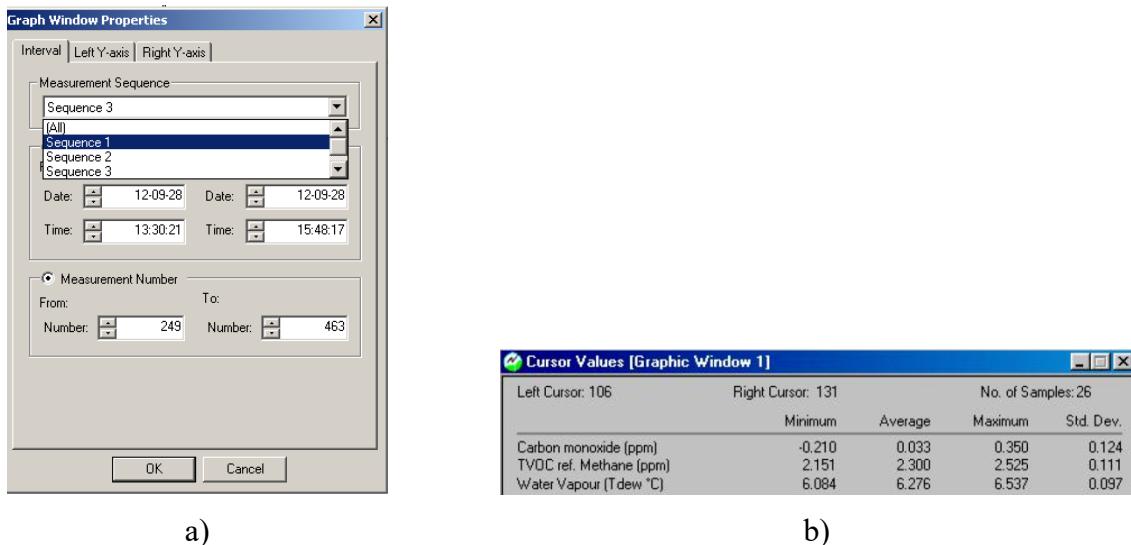


Figure 29. a) Graph Window Properties index card for Interval and b) Cursor Values Window. (1)

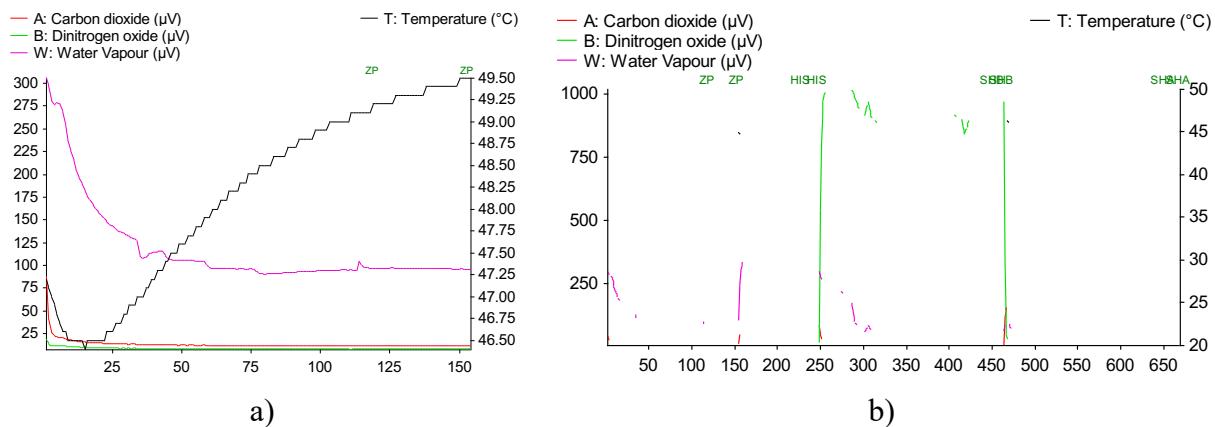


Figure 30. An exemplary graph window with interval selected for calculation for a) zero-point calibration and b) all the calibrations.

5.2. Calculating and downloading

After all the desired spans are selected the Calibration Factors can be calculated and downloaded to the Monitor.

- Pull down the *Values* menu and click on *Calculate* (Values → Calculate...). When calculations are finished the *Calculation Finished* dialogue is displayed, see Figure 31a. The window informs which Calibration Factors have been calculated and this depends only on the selected curves in Calibration Task *Graphic Window* and not on what measurements were performed. Investigate the window and click *OK*.

- The Calibration Factors are ready to be downloaded to the Monitor. Pull down the *Values* menu and click on *Download (Values → Download...)*. The Download window, see Figure 31b, will open and the correct Calibration Factors should be selected in each index card. Investigate the check boxes in the window and click *OK*.

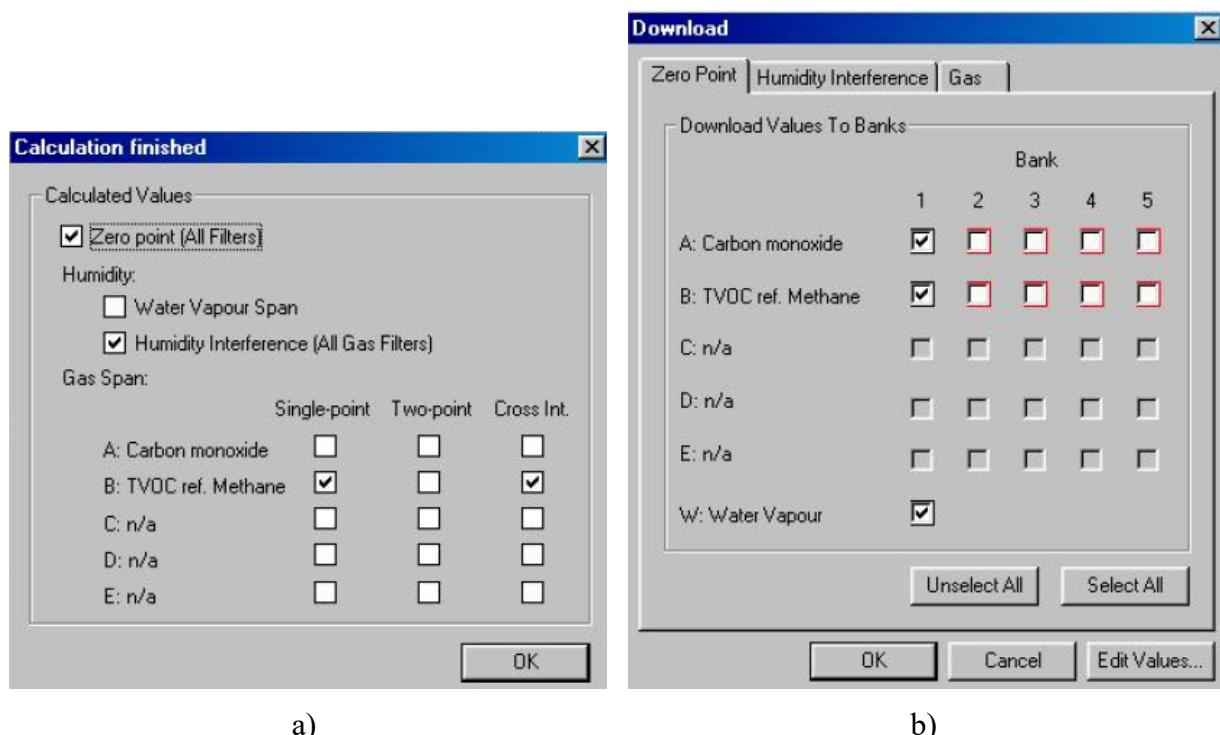


Figure 31. Dialogue windows for a) Calculation Finished and b) Download.

In the Download window there can be four possible looks of check boxes:

- The white boxes represent filter banks containing no calibration factors – you can freely enter calibration factors here without losing any existing information.
- The white boxes with a red shadow already contain calibration factors – you can download the new factors to these filter banks, but the existing information will be lost.
- The ticked check boxes with a black shadow are the computers suggestion as to where the new calibration factors should be downloaded – it is normally these positions you would select when performing a recalibration of the Monitor. However, you are free to remove the tick from the check box and place it elsewhere, or place more than one tick for a filter. Several ticks enables calibration factors to be downloaded to several banks for the same filter.
- The grey boxes – these filter banks are not available – therefore no calibration factors can be downloaded here.

6. Brüel & Kjær 1302 Photoacoustic Gas-Monitor

In this chapter the calibration procedure of *Brüel & Kjær 1302 Photoacoustic Gas-Monitor* will be explained. It should be noted that mainly the differences between this Monitor and the *Innova 1412 Photoacoustic Field Gas-Monitor* calibration are going to be presented, so it is necessary to be familiar with the previous parts of the manual to be able to perform the calibration. The main difference between these two Monitors is that during calibration of the *Innova Monitor* the calibration software is used, while to calibrate *Brüel & Kjær* only buttons on the front panel of the Monitor are used. The *Brüel & Kjær 1302 Monitor* can be seen on Figure 32. This chapter is based on *Instruction Manual* (7).



Figure 32. Brüel & Kjær 1302 Photoacoustic Gas-Monitor.

6.1. Tasks before calibration

6.1.1. Set-up Tree

For the *Brüel & Kjær 1302 Monitor* a calibration is performed on the Monitor's front panel, which is presented on Figure 32. Some of the calibration tasks can be found in the menu which can be presented as a set-up "Tree". To access the menu click *Set-Up* button on the front panel, when Monitor is ready to use. There are three main branches of *Set-Up* "Tree", which are shown on Figure 33.

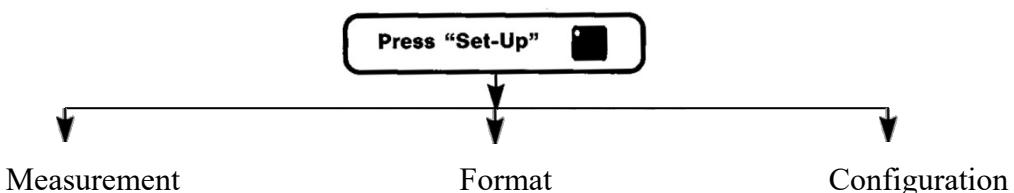
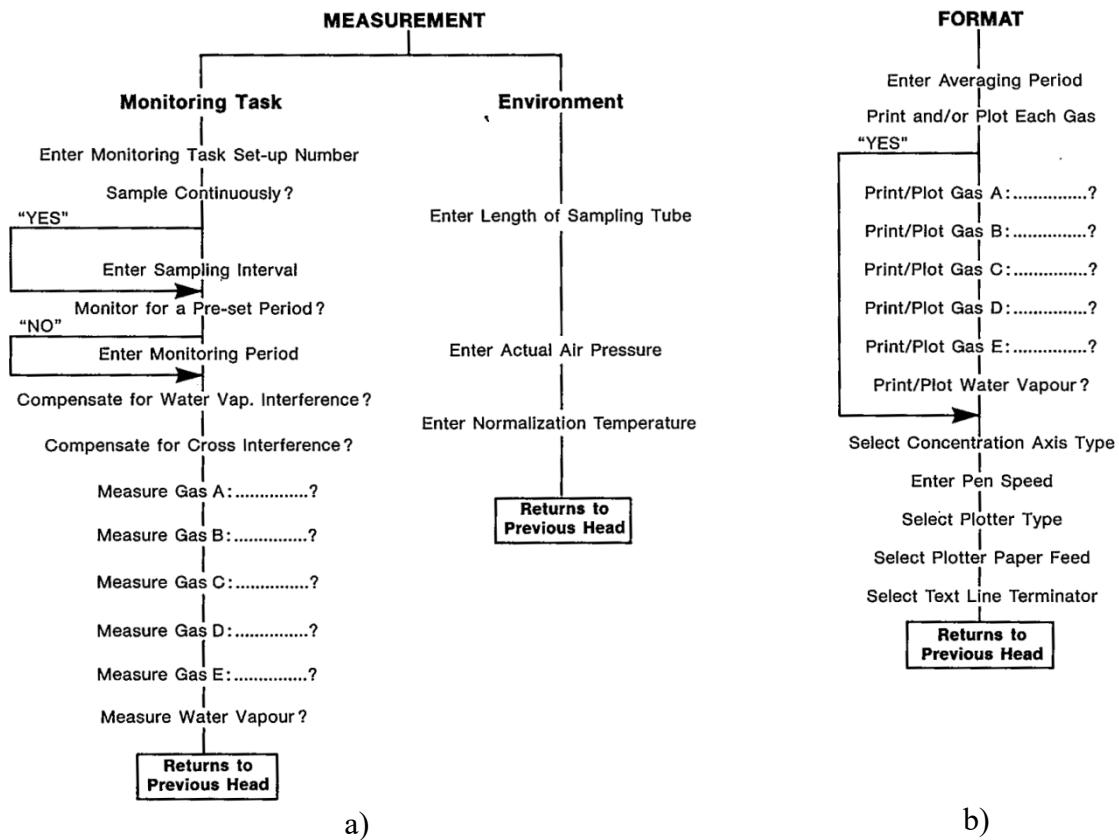


Figure 33. Main branches of the 1302 Monitor's Set-up "Tree".

- The extended *Measurement* branch can be seen on Figure 34a. The branch is used to perform the monitoring tasks. It can also be used to warm up the Monitor, which is described in section 5.1.2.
- The extended *Format* branch can be seen on Figure 34a . It is used for plotting the results and is not a part of this manual.
- The extended *Configuration* branch can be seen on Figure 35 and it is used to set-up the Monitor's parameters. The *Unit* and *Filter* parts are described in section 6.2.1.



a)

b)

Figure 34. The Set-Up “Tree” for a) Measurement and b) Format branches. (7)

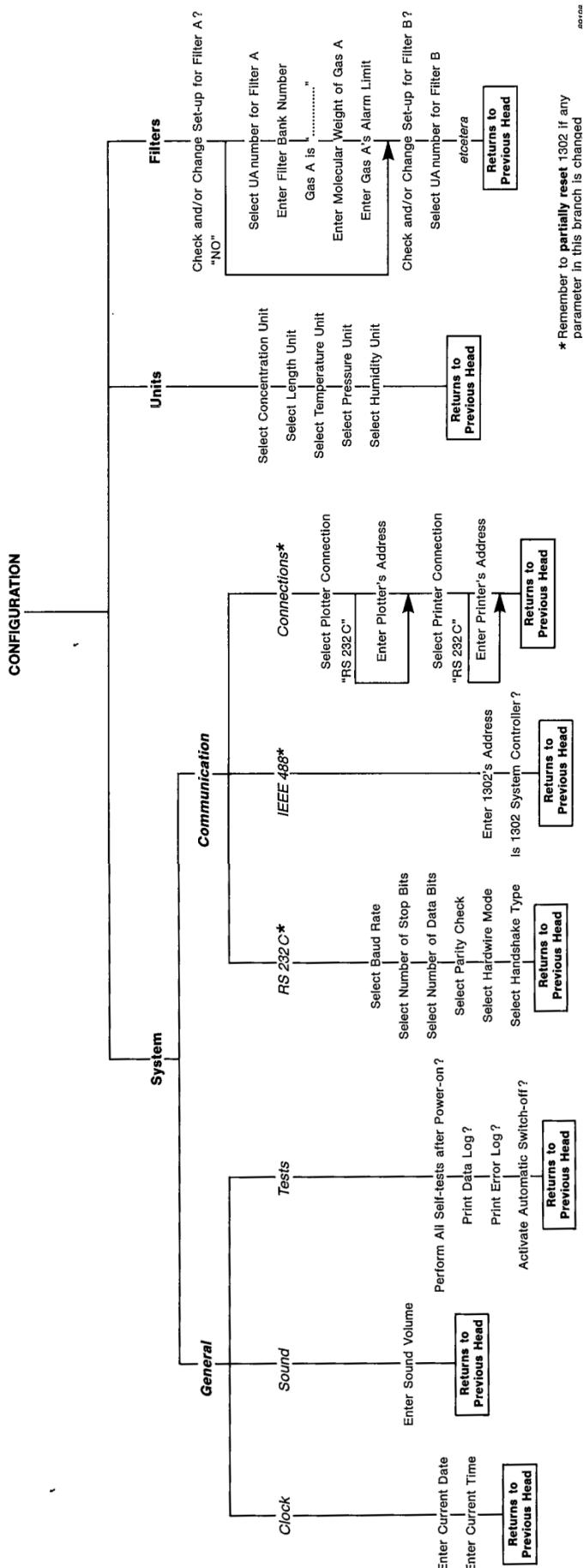


Figure 35. The Set-up “Tree” for Configuration branch. (7)

6.1.2. Warming up

To warm up the Monitor you can set-up environment measurements:

- Start the monitor and wait until it displays “Monitor is ready to use”.
- Click *Set-Up* button on the front panel and select *Measurement* and later *Monitoring task* (*Set-Up* → *S1* → *S1*).
- Edit the monitoring task in the following way (*S2* → *S3* → *S1* → *S1* → *S1*)
- Press *S1* until the text “*Measure water vapour?*” is shown on the display. Click *Yes* (*S3*).
- Select *Environment* in measurement Set-up branch (*S3*).
- Enter length of sampling tube and accept (*S2*).
- Enter actual air pressure and accept (*S2*),
- and normalization temperature and accept (*S2*).
- Click *Set-Up* button on front panel to exit menu (*Set-Up*).
- Click *Measurement* button on the front panel, later *Monitoring* and *Start Task* (*Measurement* → *S1* → *S1*).
- The monitor will now measure continuously water vapour in the environment. Let it monitor for 30-40 min.
- Stop the measurements by clicking *Measurement* button on the front panel and *Yes* (*Measurement* → *S3*). The Monitor is now ready for the calibration.

6.2. Calibration

6.2.1. General settings

Before the calibration will be set-up in the Monitor it is advisable to check the information about units and filters.

Check the units, by clicking *Set-Up* on the front panel, *Configuration* branch and *Unit* part (*Set-Up* → *S3* → *S1*). Investigate the units following the diagram presented on Figure 35.

Check the information about filters, by clicking *Set-Up* on the front panel, *Configuration* branch and *Filters* part (*Set-Up* → *S3* → *S3*). Investigate the information for the filters following the diagram presented on Figure 35. If you are only recalibrating the Monitor for the same filter positions and banks, then the names of the gases will be probably correct. If you are calibrating a new gas or an existing gas in a new filter bank, then the name of the gas and the molecular weight need to be typed in. Before changing these information contact person responsible for the Monitor.

6.2.2. Setting-up a calibration task

The description of different types of calibration tasks can be found in sections 4.3 *Zero point (N2)*, 4.4 *Humidity calibration (H₂O)* and 4.5 *Gas span calibration*. Here only practical information about setting-up different calibration tasks in *Brüel & Kjær 1302 Monitor* will be given. Below on Figure 36 can be found a general schematic diagram showing the calibration task Set-up “Tree”. When setting-up a calibration task in the Monitor you should follow the black arrows according to the type of calibration you want to perform. Exemplary schematic diagram showing how to set-up a combined cross-interference and span calibration task is shown on Figure 37. Additional schemes, if needed, can be found in *Instruction Manual (7)* in chapter 16 *Calibration of the optical filters*.

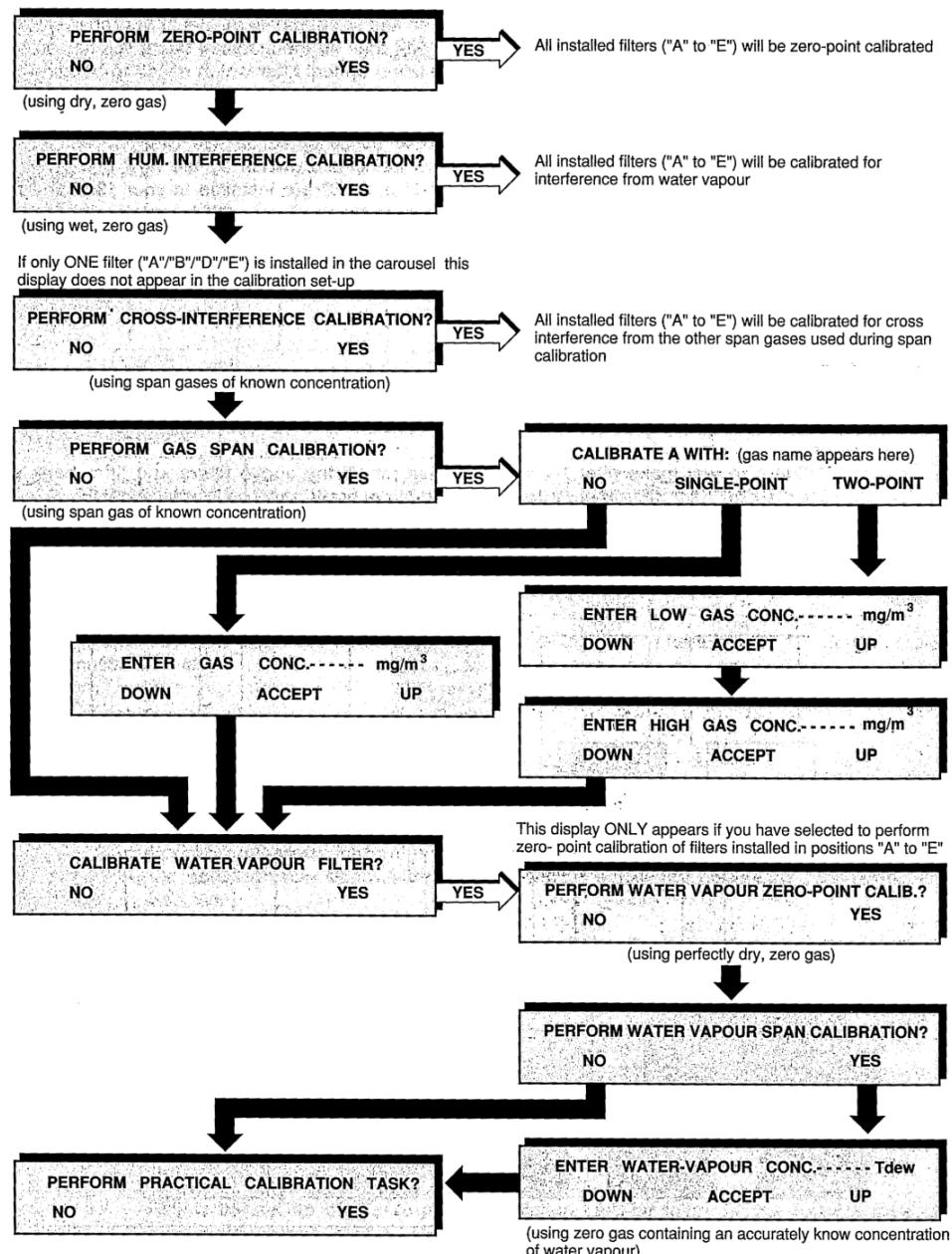


Figure 36. Schematic diagram showing the general calibration task Set-up “Tree”. (7)

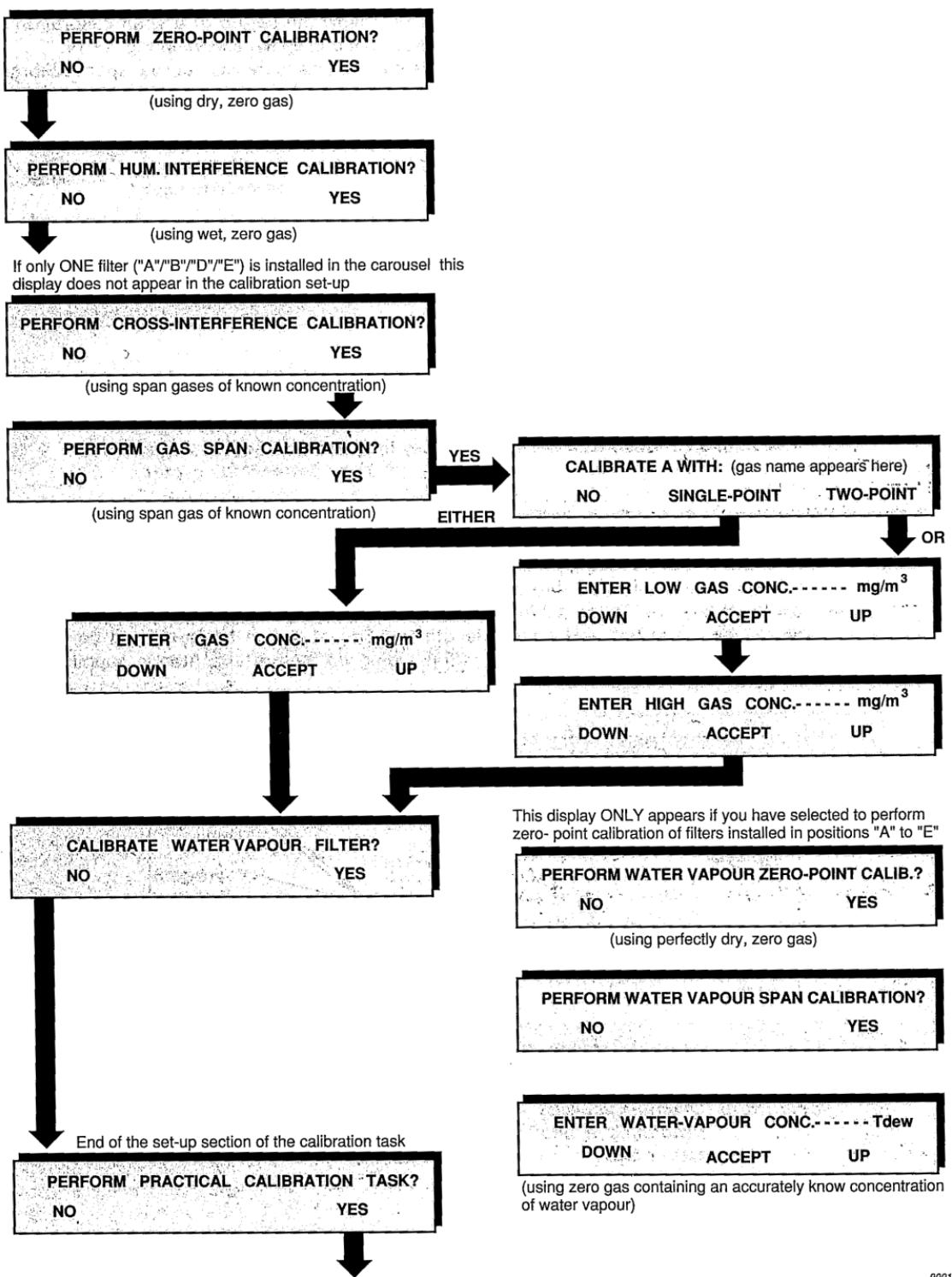


Figure 37. Schematic diagram showing how to set-up a combined cross-interference and span calibration task. (7)

6.3. Performing calibration task and calculating calibration factors

- Press *Measurement* button on the front panel of the Monitor.
- Set-up a chosen calibration task, see section 6.2.2 *Setting-up a calibration task*.
- When the calibration task settings are applied to the Monitor, a message about connecting the proper gas to the Monitor will appear. When it is done press *Enter* button.
- Once the first measurement result is available it will appear on the screen and if the printer is connected to the Monitor it will be automatically printed out on the printer. Due to lack of space on the display only one result is shown, e.g. for the zero-point calibration task the Monitor displays first only the signal measured by the water-vapour filter and you cannot scroll through the measurements. On the print-out however can be seen signals measured by all the installed filters.
- The Monitor should continue measuring until the results are stable. It is easy to track the results on the print-outs, however if the printer is not connected than it is suggested to write the results down on a paper to be able to know when the values have stabilised. When the measurement results are stable press *Enter* button. If more than one signal is measured, all the signals for different filters have to be stabilised and accepted by pressing the *Enter* button. The text “Calculating. Please wait” will appear on the screen.

It should be noted that only last 6 measurements are stored in the Monitor during any calibration. When 7 measurements have been performed, the first measurement will be overwritten by the 7th measurement. That is why the Monitor only uses the last 6 measurement results to calculate any calibration factor. If any calibration factor is uncertain or unacceptable an error message will appear on the screen after the calibration factors have been calculated and further information about the error can be obtained by pressing *Status* button. Description of error messages can be seen in *Instruction Manual (7)* chapter 18 *Appendix 1 - Messages related to calibration tasks*.

7. Measurements

In this chapter it is presented how to conduct exemplary measurements. The set-up of the equipment, software used with computer, measuring procedure and collection of the data is described. The Monitor can measure only one location at a time, so if it is planned to measure in more locations simultaneously it is necessary to use a Multipoint Sampler and Doser. Each of the Sampler and Doser can measure simultaneously in 6 locations, so two of them can measure in 12 locations. With *Gas Monitoring Software 7304* it is possible to use maximum two Sampler and Dosers, but with other software it can be extended.

7.1. Set-up

In this section set-up of the equipment for measuring task is presented. This is based on one Monitor and one Sampler and Doser, but it can easily be extended to two Sampler and Dosers. The front and back panels of the Monitor and Sampler and Doser can be seen on Figure 39. To prepare the equipment:

- Connect outlets from back panels, namely *Outlet* in the Monitor and *Waste Air Outlet* in the Sampler and Doser, to external air by Teflon tubing.
- Connect *Outlet to Analyser* from back panel of the Sampler and Doser to *Inlet Air Filter* located on the Monitor's back panel by Teflon tubing.
- Connect the Monitor to the Sampler and Doser by *IEEE-488*, *GPIO*, cable presented on Figure 40a.
- Connect the PC with installed software to the Monitor with a cable presented on Figure 40b, *COM* port in the Computer and *RS-232-C* port in the Monitor. Remember that special USB flash drive, see Figure 41a, with a key to the software should be inserted to the Computer.
- Set a *Device Address* that is used to communicate with specific Sampler and Doser. The switches are located on the back panel of the Sampler and Doser and can be seen on Figure 41b. Normally number 15 can be used for first Sampler and Doser and number 16 for second.
- Connect Teflon tubing used for sampling, maximum six tubes for one Sampler, to the Sampler and Doser in the Sampler field, see Figure 39a.
- Plug both, the Monitor and the Sampler and Doser, to electric sockets.
- Turn on the Monitor and Sampler and Doser.
- Turn on the Computer.
- Turn on the *Gas Monitoring Software 7304*, see icon on Figure 38.



Figure 38. Gas Monitoring Software 7304 icon.



a)

b)

Figure 39. The Monitor and Multipoint Sampler and Doser a) front panel and b) back panel.



a)

b)

Figure 40. Cables used to connect a) the Monitor and the Multipoint Sampler and Dosser and b) the Monitor and the Computer with software.



a)

b)

Figure 41. Pictures presenting a) USB flash drive holding serial number and key to the software and b) close-up on the Multipoint Sampler and Dosser's back panel with switches for Device Address with selected binary address number 15.

7.2. Gas Monitoring Software 7304

7.2.1. Setting up measurements

When the software is ready to use a window shown on Figure 42a can be seen. In this section measurements using *Gas Monitoring Software 7304* are described.

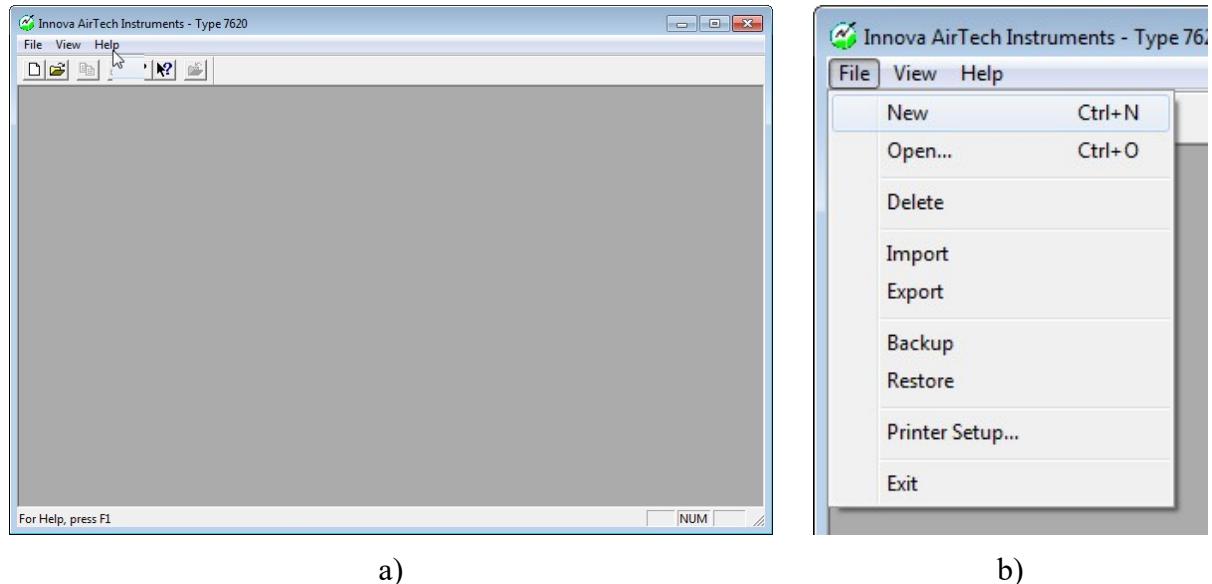


Figure 42. Picture showing a) starting window and b) creating new file.

- A *New Calibration Task* can be created from *File* menu (*File* → *New*), see Figure 42b, and the name can be chosen, see Figure 43a,
- Or an old Calibration Task can be *Opened* by selecting *Open* from *File* menu (*File* → *Open*) and the file can be chosen from the list, see Figure 43b.
- When ready click *OK*. The next steps should be proceeded only for the new file.

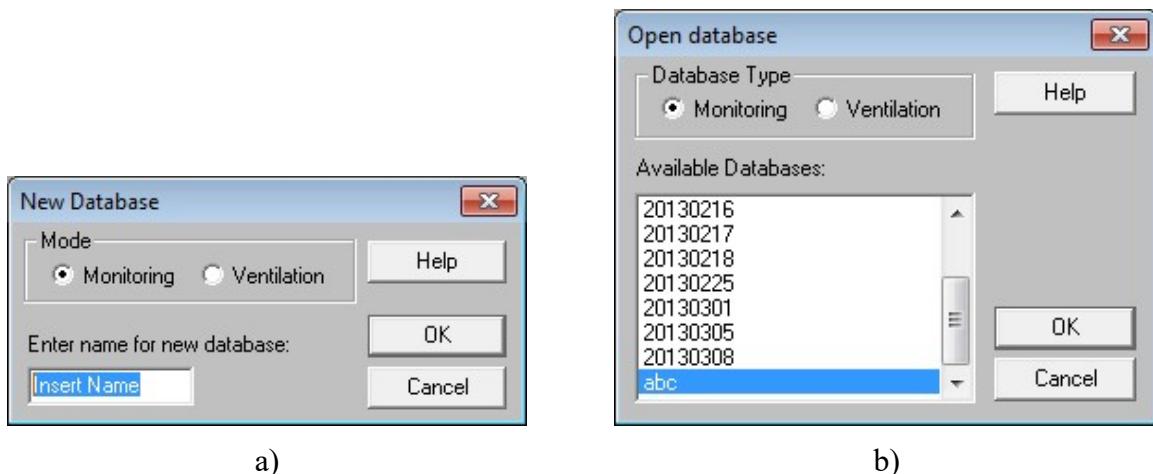


Figure 43. Pictures presenting windows a) New Database and b) Open Database.

- A new menus should be available, namely *Edit*, *Set-up* and *Measurement*.
- Select *Set-up* menu and click on *Configuration* (*Set-up* → *Configuration*), see Figure 44a. Select type of communication with the Computer and number of used Sampler and Dosers in *Connected Multiplexers* field, see Figure 44b. Click *OK*

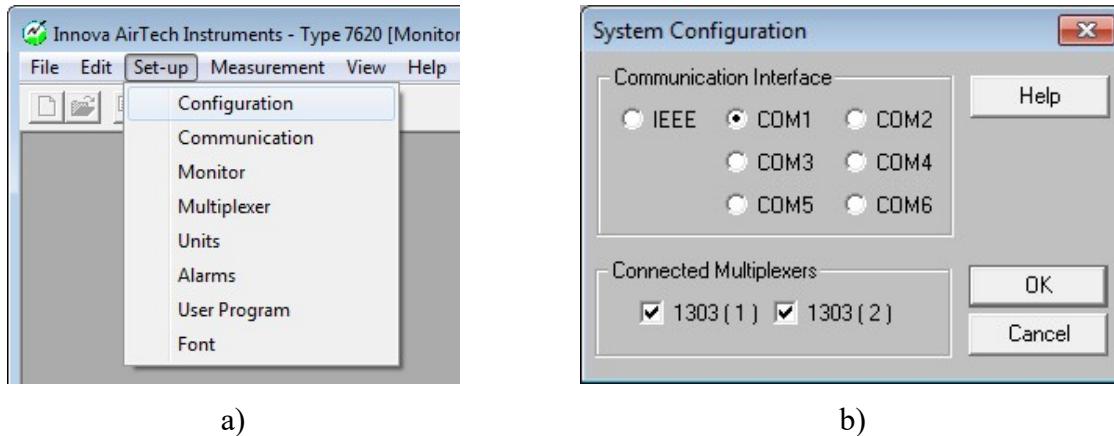


Figure 44. Pictures presenting a) Configuration menu b) Configuration window.

- Select *Set-up* menu and click on *Communication* (*Set-up* → *Communication*), see Figure 45a. Select type of communication with the Monitor and Sampler and Dosers. Choose Monitor communication according to information shown on Figure 19 or Figure 45b. Green dots represent configuration for Innova 1412 Photoacoustic Field Gas-Monitor, and orange dots represent configuration for Brüel & Kjær 1302 Photoacoustic Gas-Monitor. Choose the values carefully depending on the used Monitor. Select Devices Address for the Monitor to 14 and for Sampler and Dosers respectively to Set-up, normally 15 for the first and 16 for the second, see Figure 45b. Click *OK*.

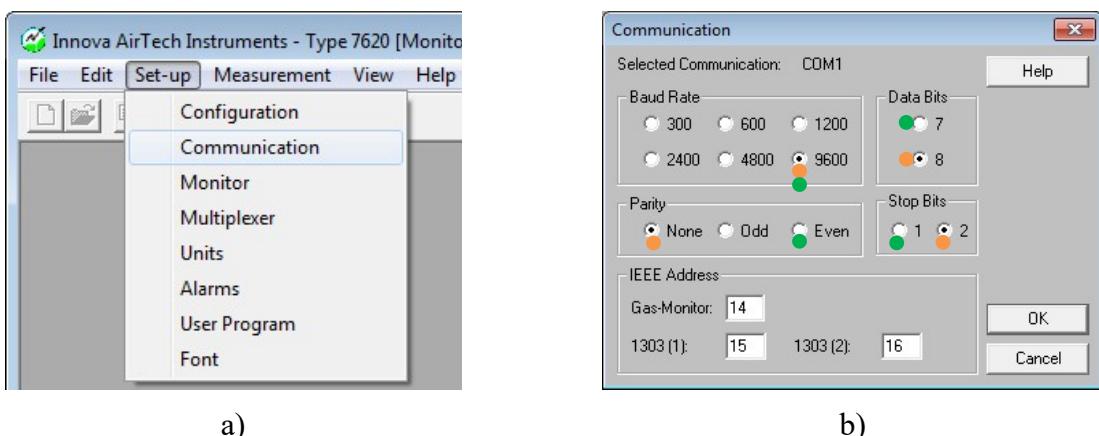


Figure 45. Pictures presenting a) Communication menu and b) Communication window.

- Select *Set-up* menu and click on Monitor (*Set-up* → *Monitor*), see Figure 46a. Click on *Read* button in *Gas-Monitor Set-up* window and wait until the information from the Monitor is received, which means that the names of the gases should be seen now, see Figure 46b. Select sampling interval, compensation type, choose normalization temperature equal to 0 °C and correct air pressure. Finally choose the filters that should measure the concentration. Click *OK*.

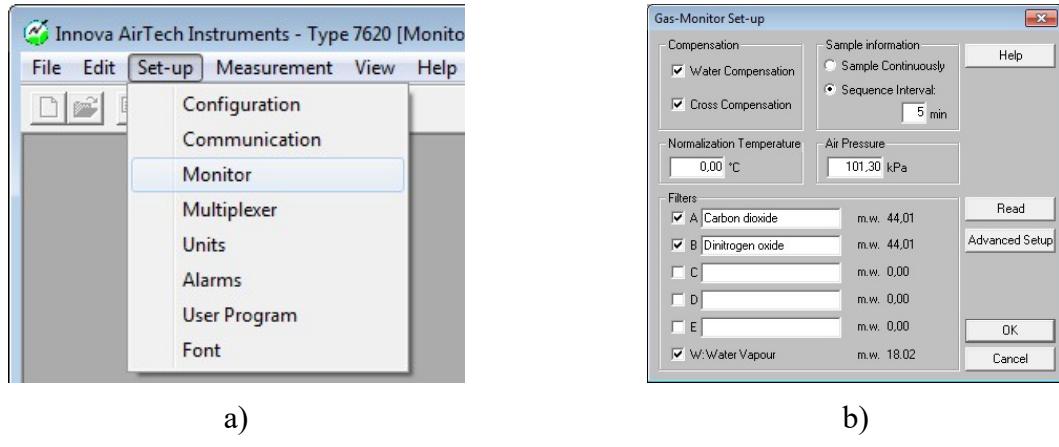


Figure 46. Pictures presenting a) Monitor menu and b) Gas-Monitor Set-up window.

- Select *Set-up* menu and click on *Multiplexer* (*Set-up* → *Multiplexer*), see Figure 47a. In *Multiplexer Set-up* window select *Sample Channels* for Sampler and Dosers that should be used for measurements, see Figure 47b. Click *OK*.

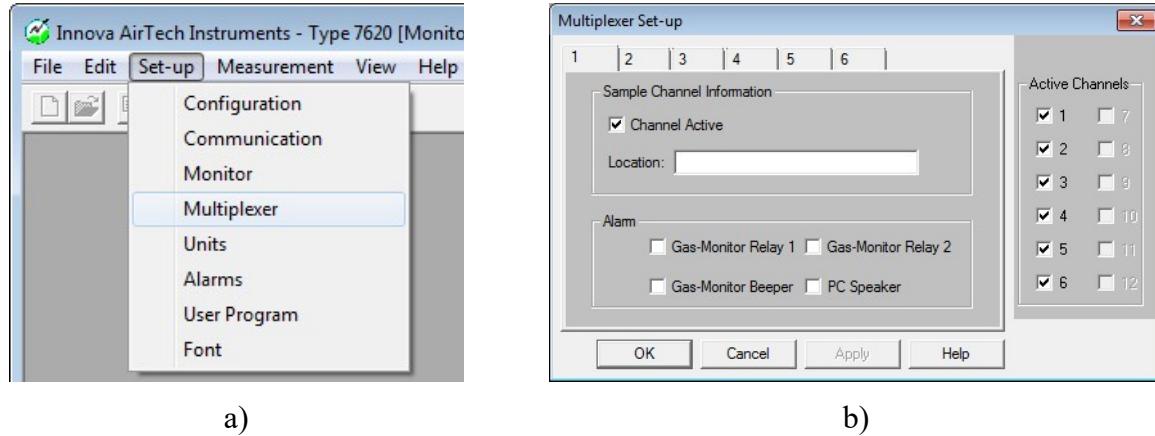


Figure 47. Pictures presenting a) Multiplexer menu and b) Multiplexer Set-up window.

- Finally select *Set-up* menu and click on *Units* (*Set-up* → *Units*), see Figure 48a. It is advised to check units which are used. Examine the *Units* window that is displayed, see Figure 48b. Gas concentration can be selected to parts per million (ppm) and water vapour concentration to absolute humidity (mg/m³). Click *OK*.
- Now the software is ready to use for measuring gas concentration.

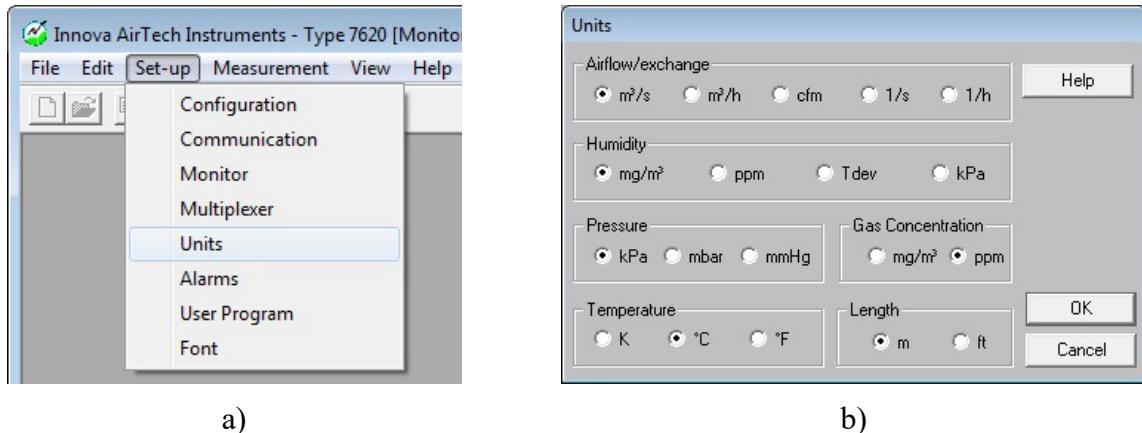


Figure 48. Pictures presenting a) Communication menu and b) Communication window.

7.2.2. Starting and stopping measurements

- To start the measurements select *Measurement* menu and click on *Start* (*Measurement* → *Start*), see Figure 49a.
- You can see the measurements in *Graphic Window*. Select *View* menu and click on *Graphic Window* (*View* → *Graphic Window*), see Figure 49b. The *Graphic Window* should appear on the screen, see Figure 50. On the left side of the window there are buttons for setting up the graph, namely *Graph Setup* and *Data Select*.

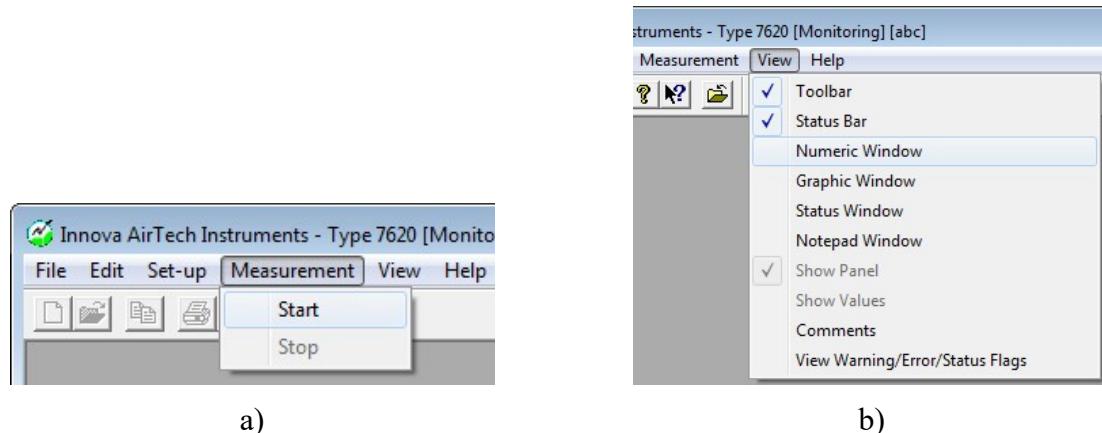


Figure 49. Pictures presenting Pictures presenting a) Start menu and b) Numeric Window menu.

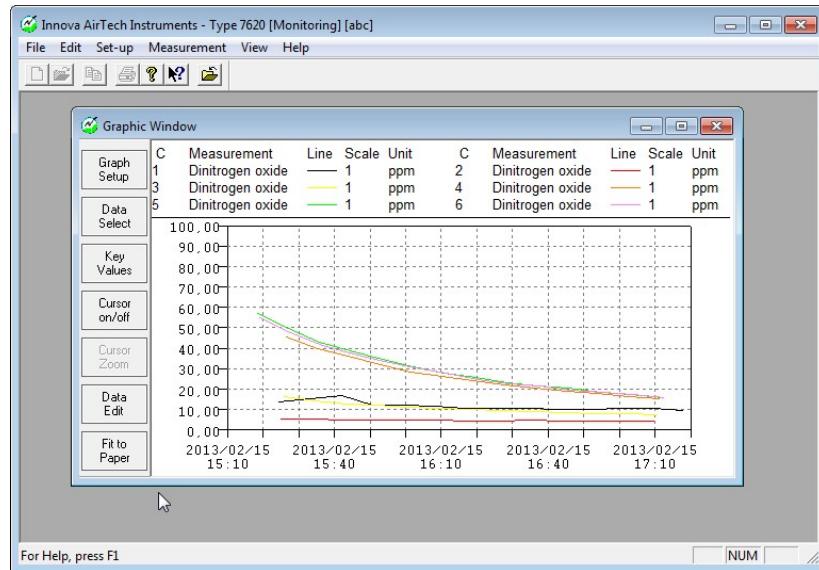


Figure 50. Graphic Window.

- To set up the axes of the graph click on *Graph Setup* button. In *Graph Parameters* window scale and range of the axes can be changed. To change the time span that is shown change values in *X-interval* square, see Figure 51a.
- To set up channels, lines' type and color, filters and shown values click on *Data Select*. In *Select data to show on graph* window, see Figure 51b, you can switch on and off the channels by double click on them and edit them clicking on channel and changing the values. Additional information can be found in *Channel Data* window, see Figure 51b, which can be accessed by *Data* button.

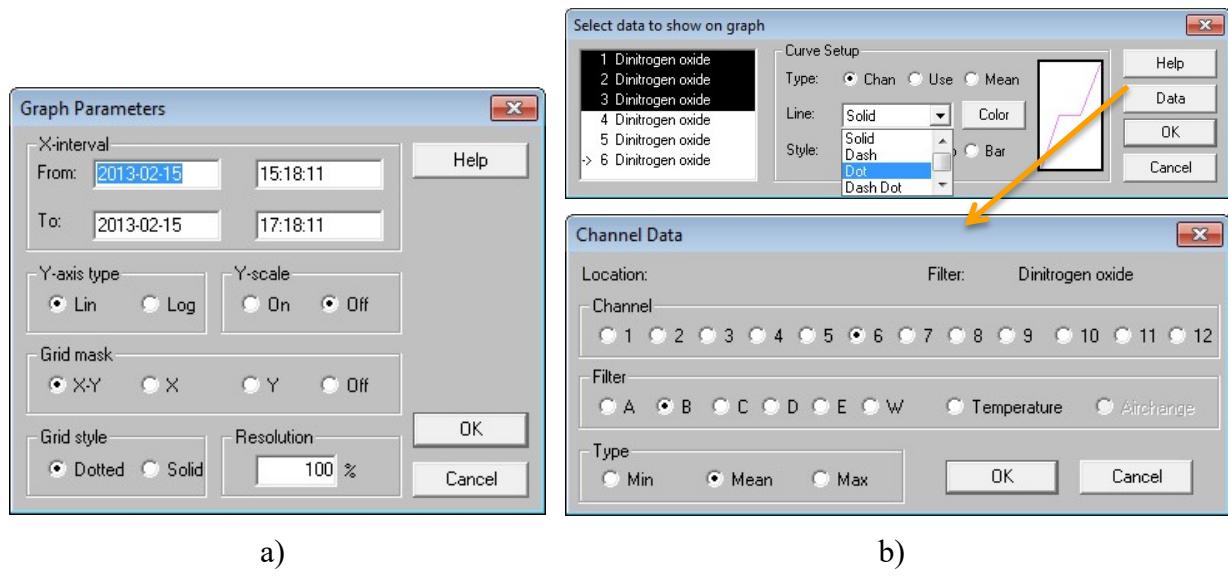


Figure 51. Picture presenting a) Graph Parameters window and b) Select data to show on graph and Channel Data window.

- To stop measurements select *Measurement* menu and click on Stop (*Measurement* → *Stop*), see Figure 49a.

7.2.3. Collecting data

- Data can be copied from *Numerical Window*. Select *View* menu and click on *Numeric Window* (*View* → *Numeric Window*), see Figure 49b.
- *Numeric Window* presents time and concentration in two columns, see Figure 52. The data can be copied from the window or printed to PDF file and then transferred to other computers.

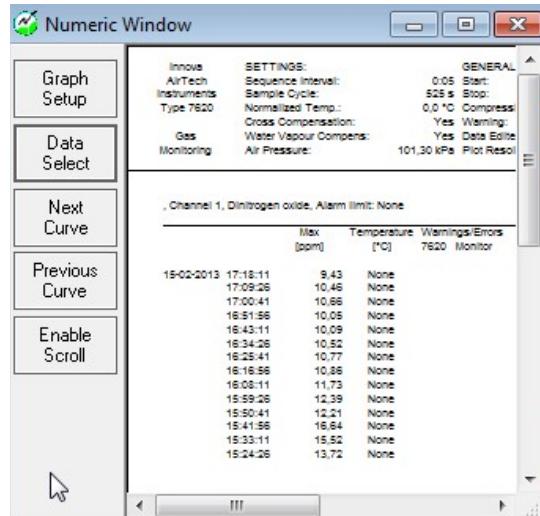
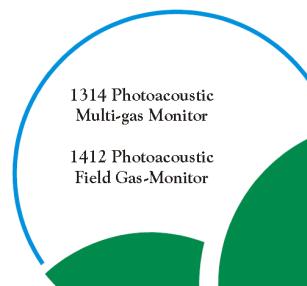


Figure 52. Picture showing Numeric Window

8. Bibliography

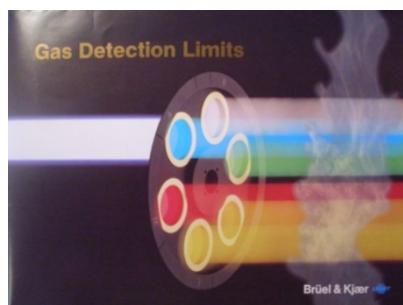
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(1)



(4)



(3)



(2)

