FLUE GAS ANALYSER GA-12

Operating manual

Ver. 0.43
09/2006

madur®

E L E C T R O N I C S

1   MAINTENANCE

Sensors

The following points will extend the lifetime of the gas sensors and ensure that measurements are carried out without errors:

- Do not apply a gas concentration greater than the range of the sensor.
- The sensors can react unpredictably to chemicals that are not typically found in flue gases. For this reason the equipment should not be cleaned with chemical solvents. The vapour produced by such solvents can lead to destabilisation and even permanent damage to the sensors should it penetrate into the gas chamber.
- Some sensors have a voltage applied to them even when the analyser is switched off. Please be sure that there are always charged batteries in the analyser.
- Do not switch the analyser off before the gas system is free of flue gases.
- Keep the analyser in a cool place if it is to be left for some time. This will reduce the wear on the sensors.

Gas system

An in-line filter protects the gas system. The filter element will become dirty with use and should be changed when necessary. The water that condenses in the trap should be emptied as required.

Batteries

The instrument uses 4 AA type batteries (1.5 V).

If the instrument is not in use for some time, then the battery will nevertheless be consumed since certain circuits are permanently in use. For this reason the state of charge of the batteries should be checked monthly at least.

Service times

It is essential to carry out a periodical service since the parameters of the gas sensors change with time. During this service the gas sensors should be calibrated with standard gas. We recommend that service be carried out every 6 months.

Errors

The instrument has a self-check function. Should an error occur it will be shown on the screen **CONTROL LIST**.

Switching off after use

The life of the electrochemical sensors depends on the use of the instrument. Wear on the sensor is greater at higher gas concentrations and during longer measurements. This leads to a slow deterioration of the sensor.

For this reason the instrument should not be switched off until all the flue gases have been purged from the system with clean air and the instrument has been allowed to run in air for a few minutes.

2   OPERATION

2.1 Use of the keyboard

Description of the keys

- Left function key. Carries out the function shown on the display whilst the instrument is switched on.

- Right function key. Carries out the function shown on the display whilst the instrument is switched on.

- Centre function key. Carries out the function shown on the display when the instrument is switched on. Switches the instrument on.

- Starts a printout.

- Switches the instrument off.

- On a results screen calls the option *Chart*, in text mode shifts the cursor to the left.

- On a results screen calls the option *Menu*, in text mode shifts the cursor to the right.

- Moves the cursor upwards in a menu. In text mode increases the value. On a results screen chooses the next screen.

- Moves the cursor downwards in a menu. In text mode decreases the value. On a results screen chooses the next screen.

Entering numbers

Numbers are entered as follows:
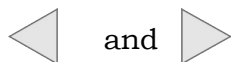
and   - move the cursor backwards or forwards to the digit to be changed.
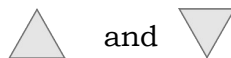
and   - increases/decreases the value of the marked digit.

2.2 Basic operation

Getting started

Connect the individual parts of the instrument:

- connect the probe.
- ensure that the gas outlet is not blocked.

Switching on

Check the filter before switching on. Clean or replace as necessary.

Zero calibration

The instrument performs a zero calibration immediately after being switched on.

During zero calibration the probe must be outside the flue gas channel.

This process is essential for the accuracy of the measurements. This process calibrates the oxygen sensor to 20.95 % in clean air and sets the zero point of the toxic sensors. The icon in the top-left corner of the screen represents the battery charge level.

```
┌─────────────────────────────┐
│ ▬              15:03:11      │
│      Initial calibration     │
│                              │
│           ███               │
│            1                │
│                              │
│         Please wait...       │
└─────────────────────────────┘
```
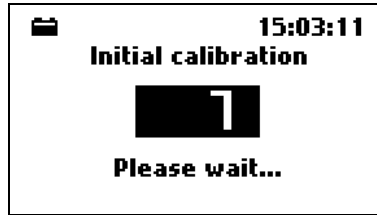
After the zero calibration the **Options** menu opens automatically. Here the measuring parameters can be checked or changed. See also pt. Measurement parameters.

```
┌─────────────────────────────┐
│ Options                 I   │
│ ▶ Averaging time:      2s   │
│   Reference O2:        3%   │
│   Fuel                 5    │
│        Extra light oil      │
│ ▮Esc      Change        II▮ │
└─────────────────────────────┘
```
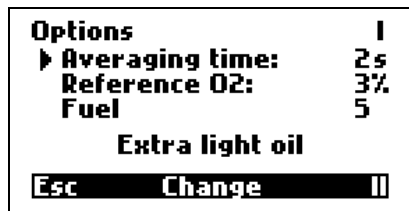
2.3 Results screens

The function keys **Data** or **Esc** will automatically call up the results screen from any point. Below is an example of a results screen.

Explanation:

The Info bar

The Info bar is at the top of the screen. The signs have the following meanings:

- The number **1** stands for the first results screen. Four results screens can be defined. These can be called up using the up and down keys.
- **M2** shows how many memory spaces are still available. In this case, 2 of the 16 reports are still empty.
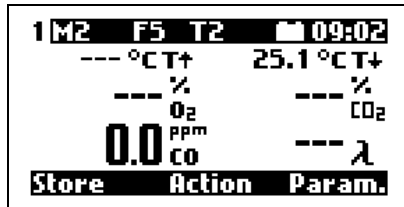- **F6** shows the chosen fuel. The instrument contains 6 fixed and 4 programmable fuels. These are numbered 0..9.
- **T2** shows the set averaging time. This can be programmed in fixed steps between 2 and 180 seconds.
- **Battery:** this shows the state of charge of the battery.
- **09:02** shows the current time as set in the analyser.

The menu bar

The menu bar at the base of the display shows the use of the function keys. The possibilities are explained under "MENU".

Results

All the results of measurements and calculations are shown as averaged values. Averaging time is chosen by the user under **Parameter** from 2 – 10 – 20 – 30 – 60 – 120 – 180 seconds, for example, the choice of 60 seconds means that the average of the last 60 seconds is shown on the display.

The user can define the content of the individual results screens. The necessary software, "PCGA12plus", is to be found on the utility disk. There are also a few examples of the possibilities there (ResScreens_1.bin …ResScreens_4.bin).

Here is a list of all measured or calculated variables that can be shown on the results screens:

4 - Volumetric concentration of the gases: O_2, CO, NO_x und CO_2

2 - Undiluted volumetric concentration of the gases. CO_u, NO_{xu}

4 - Mass concentration of the gases:

absolute: CO_m, NO_{xm}

relative, related to a defined level of rest oxygen: CO_{rel}, NO_{xrel}

2 – Emission of the gases related to the energy value: ECO, ENO_x

7 – Combustion parameters: SL, Sco, ETA, ETA*, Lambda, TI, EA

3 - Temperatures of the gas, environment and inside of the analyser.

2 - Pressure/differential pressure and flow rate

1 - Relative humidity of the gas in the analyser.

1 – Battery voltage

3   MENU

From the results screens the following options can be activated with the keyboard:

- Store – the left function key.
- Action – the centre function key.
- Parameter – the right function key.
- Chart – the arrow left key.
- Menu – the arrow right key.
- Print – the printer key.
- Switch off – Pressing the round, red key will switch the instrument off completely.

3.1 Storing results

The option **STORE** can be reached from any results screen by pressing the left function key. The results on the screen are stored in a buffer and remain there until stored permanently. The results are stored in the form of reports. This is a collection of all the results. If the report should also include the chimney draught, then this measurement must be carried out before storing the results. Opening the option calls up the following screen:

```
Store?                 16
   Averaged results
▶ Single XL test
   Triple XL test        ⍩
         10sec * 1
 Esc        OK       Data
```
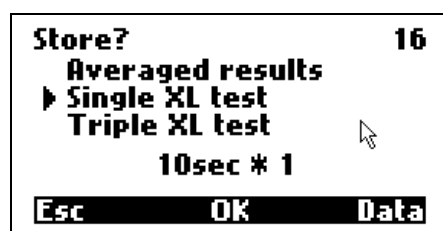
Results can be stored in three different ways:

Averaged results

The averaged results will be stored. The averaging times that can be set under **Parameter I** are 2, 10, 20, 30, 60, 120 and 180 seconds.

Single XL test

The averaged results will be stored. The term XL (extra large) is used for the formation of especially long averages. XL test time's can be set via Parameter **II screen** or on current screen using keys:

◁ and ▷ Available times: 10sec, 20sec, 30sec, 1min, 2min, 5min, 10min, 15min, 20min, 30min.

Triple XL test

This will automatically store three consecutive **single XL Tests**.

During storage of XL test, battery charge icon is replaced with the number of current test (X1, X2, X3) and the clock counts down the time, till the end of test. During the XL test the analyser beeps every two seconds.

In the top-right corner the number of available reports is shown.

If the memory of analyser is full, and no more reports can be stored the following screen is shown when the storage is attempted.

```
Report building
┌─────────────────────┐
│                     │
│    No free reports! │
│  Overwrite oldest one? │
└─────────────────────┘
Esc        Yes
```
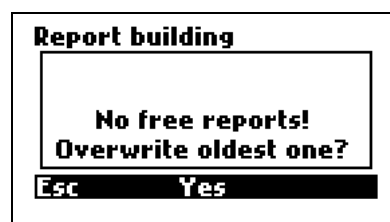
ESC

The storing of results will be stopped and the instrument returns automatically to the results screen.

YES

The oldest report(s) will be deleted and the new one(s) stored instead.

If the results are to be stored, then the instrument will request a customer number (identification number of the report). This number will appear on the report.

```
┌─────────────────────────────────┐
│ Report building                 │
│  Enter customer number          │
│         ┌──────────┐            │
│         │  0113    │            │
│         └────▲─────┘            │
│ Esc       OK             C      │
└─────────────────────────────────┘
```

When the number has been entered and confirmed with "OK", the following screen will appear momentarily.

```
┌─────────────────────────────────┐
│ ┌─────────────────────────────┐ │
│ │ ▪                           │ │
│ │ ▌                           │ │
│ │      Report saved...        │ │
│ │        #00026               │ │
│ └─────────────────────────────┘ │
└─────────────────────────────────┘
```

This completes the storing of the results and the instrument will return automatically to the results screen. The number that appears on the confirmation screen #00026 is not the report number (1...16), it is the activity counter that is automatically attached to the report by the instrument.

There is a possibility to stop and shorten the XL test. If the function key [◣] is pressed during the single XL test or during the X1 test (the first test of triple XL test) then the measurement is stopped and result is not stored. If the function key [◣] is pressed during the X2 or X3 test, the measurement is disrupted but its result will be stored.

During the XL test, the result can be viewed. Pressing the [❙] key during display of the result screen will call up the XL test results for a few seconds (Averaged for the time since the beginning of the test).

3.2 Action

This useful tool comprises a list of simple commands. Pressing the centre function key [❙] on the results screens opens this option.

```
┌─────────────────────────────────┐
│ Action                          │
│ ▶ HOLD - ☀                      │
│   Pressure s. zeroing           │
│   Capture pressure value        │
│   Calibrate O2 for 20.95%       │
│   Ambient CO test               │
│ Esc       OK          Data      │
└─────────────────────────────────┘
```
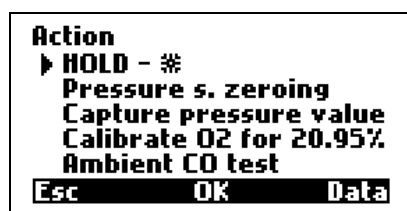
HOLD - *

The present measurement values are frozen and the screen will spring automatically to the frozen values. Pressing the centre function key ![I] again will end the freezing of the values and the instrument will return to showing the present values. Hold mode is signalised by flashing * sign over the middle function key.

Holding the measurement can stop the pump. Settings are made using the option "Pump stop when hold" with the help of the PCGA12plus programme. If this option is marked every test hold turns the pump off until it is restarted.

Pressure/ draught zeroing

This sets the pressure sensor to zero. The current pressure value is set as the zero level. This must be carried out before every pressure measurement. The instrument should be held in the same position during measurement as was used during zeroing.

Capture pressure value

The currently presented on the results screen pressure value will be stored in the device's memory and can be included in the next printout, stored in the next report or replaced by a newly measured pressure value. Each of those processes will lead to the loss of the currently stored pressure value.

Calibrate O2 for 20.95 %

The GA-12 has the possibility of calibrating the O2 sensor with clean air in order to increase the accuracy of measurement when the instrument has been in use for some time. Do not forget to remove the probe from the stack and wait for a stable reading.

Ambient CO test

This option is used to measure the ambient CO level. The instrument will request that the probe is removed from the stack. After confirmation the measurement will begin. The measured value of ambient CO will be shown on a result screen and will appear in the next printout or be stored with the next report as "Ambient CO".

3.3   Chart

The instrument stores the last 100 values of the 2-second averaging in the RAM. The chart will show the values for the last 190 seconds. The most recent value is on the right-hand side, the oldest on the left. The diagram will scroll from right to left with time.

A screen similar to the following will appear:

the signs on the left have the following meanings:

- Maximum value of the Y axis (here 21).
- Current value or, when the marker is activated, the marker value (here 20.33).
- The unit (here %). This appears automatically with the variable.
- The variable (here O_2). The arrow up/down keys can be used to scroll through the variables.
- Marker time (here –22s). This means the marker stands on the value that was recorded 22 seconds earlier.
- Minimum value of the Y axis (here 16.70)

The menu bar:

ESC

Leave the *Chart* and return to the results screen.

Sign II

Burner regulation - this option is not yet available.

Option

This opens the window for the ***Chart*** settings. The following screen appears:
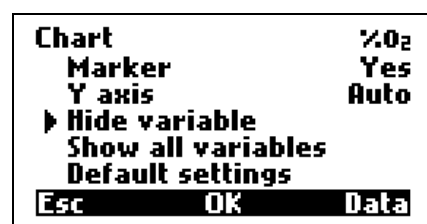
Marker

Switches the marker on or off.

Y Axis

The scale system for the Y-axis can be set. These are the options:

- Automatic scale – the instrument chooses the scale according to the measured values.
- Manual – the scale can be set by the user with the PC programme.
- Full – The whole range of the sensor is shown.

Hide variable

After confirmation with *OK* the variable will no longer be shown on the Chart. Can be re-activated using **show all variables** or with the PC programme.

Show all variables

After confirmation with *OK* the instrument will show all measured and calculated variables on the Chart.

Default settings

After confirmation with *OK* the instrument will show some important measured and calculated results: O_2, CO, ETA, Lambda, Tgas.

3.4 Measurement parameters

The arrow left will access *Parameter* from the results screens.

The following screen appears:

```
Options                    I
  Averaging time:        2s
  Reference O2:          1%
▶ Fuel                   9
          User Fuel1
 Esc      Change        II
```

Averaging time

The following averaging times can be set using the function key *change* or the arrow left/right:

2 – 10 – 20 – 30 – 60 – 120 – 180 seconds.

Reference oxygen

Using left/right arrow keys averaging oxygen can be set exact to a percent from 0 to 13 %.

If option "ŐNORM" or "Use O2ref from fuel data" was ticked in the service program there is no way to change the reference oxygen, this value is adopted from defined fuel parameters.

Fuel

The following 6 fuels can be set using the function key ***change*** or the arrow left/right:

Light oil

Natural gas

Town gas

Coke-oven gas

Liquid gas

Extra light oil

There are also 4 memory locations for 4 fuels programmed by the user. This is carried out using the PC programme.

It is possible to replace the first six standard fuels with the set of fuels recommended by OENORM. To use the Austrian set of fuels tick option "OENORM" in PCGA12plus programme.

Using of the Austrian set of fuels will automatically switch the mode of the oxygen reference choice off (the value will always be taken from fuel's parameters).

The Austrian fuels:

0- Erdgas

1- Flüssiggas

2- Heizöl HEL

3- Heizöl EL

4- Holz

5- Kohle

Using the II function key displays the following screen:

```
┌─────────────────────────────┐
│ Options              II      │
│ ▶ XL test          20 sec    │
│                              │
│                              │
│ ▐Esc▌    Change      ▌       │
└─────────────────────────────┘
```

XL test

Using the Change key or arrows left/right allows the user to set the XL test time. The following values are available:

10sec - 20sec - 30sec - 1min - 2min - 5min - 10min - 15min - 20min - 30min

3.5 Menu

This option can be accessed from the results screen with the help of the arrow right key ▷ .

```
Menu                08:58
 ▶ Settings
   Reports
   Clock
   Service

 Esc        OK       Data
```

3.5.1 Settings

The following options can be reached from the *Settings* menu.

```
Settings
 ▶ Pressure unit    mmH2O
   Temp. unit          °C
   Language        English


 Esc      Change     Data
```
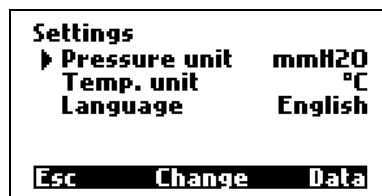
Pressure unit

The following pressure unit are available: hPa, Pa, mmH2O and inH2O.

Temp. unit

The temperature measurement can be presented in the following values: °C and °F.

Language

The instrument is pre-programmed with a number of languages. The language will generally be set at the factory to match the client's needs. In case of an accidental language change (when having problems with finding the proper setting in the analyser's menu) it is possible to restore the default language by pressing ▢ key when starting the analyser. The choice of the default language is made with the PCGA12plus programme.

3.5.2 Reports

This option allows administration of the stored reports.

```
 Reports                0
┌────────────────────┐
│ 15. 14/06 K0001 1/1 ▲│
│▶16. 14/06 K0001 1/1 ║│
│ 01. 14/06 K0001 1/1 ▼│
└────────────────────┘
    12:32 #0021 T002
 Esc      Print     Erase
```
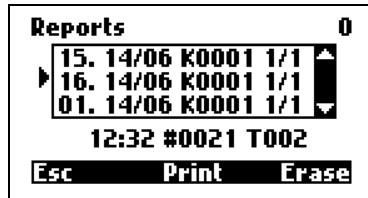
The user can preview the report contents by pressing the arrow right key when the cursor points on the chosen report. Each of the report contains of two screens which can be evoked by pressing the right function key (II or I). The bar on the top of the screen informs the user whether the chosen report is a single one (1/1) or the first, the second or the third one of the triple XL test (1/3; 2/3; 3/3). In the left column the measurement results of the chosen test appear. The middle column contains the information on the averaged results of the triple XL test. (If the report concerns the single measurement the two columns will not differ – see the example below on the right-hand side). Pressing the centre function key (1-2-3) enables the user to switch between the three reports of the triple XL test. The right function key (II/I) displays the other screen with the contents of the chosen report.

```
┌────────────────────┐  ┌────────────────────┐
│  1/3      Triple    │  │  1/1      Triple    │
│     27 │     27 │°C T+│  │     26 │     26 │°C T+│
│    --- │    --- │°C T+│  │    --- │    --- │°C T+│
│   18.4 │   18.4 │%O₂ │  │   21.0 │   21.0 │%O₂ │
│   1336 │   1336 │ppmCO│  │      0 │      0 │ppmCO│
│    --- │    --- │ppm NO│  │    --- │    --- │ppm NO│
│ Esc    1-2-3      II │  │ Esc    1-2-3      II │
└────────────────────┘  └────────────────────┘
```
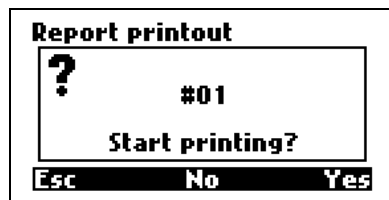
Using the Print key in the Reports menu displays the following screen:

```
┌────────────────────┐
│ Report printout     │
│ ?                   │
│ ·       #01         │
│                     │
│   Start printing?   │
│ Esc      No      Yes│
└────────────────────┘
```

Choosing ESC or No returns to previous screen, choosing Yes starts printing.

If chosen report is the one from the triple XL test report, the following screen is displayed:

```
┌────────────────────┐
│ Report printout     │
│ ?                   │
│ ·       #03         │
│                     │
│   Start printing?   │
│ Esc     Triple   Yes│
└────────────────────┘
```
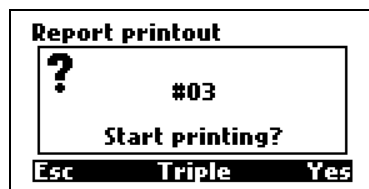
Choosing Triple causes averaging and printing all three parts of triple report as a whole.

Check if the printer is on and it's receiver is near the upper edge of the analyser.

To erase the report use the Erase button; the confirmation screen will be displayed.

```
┌──────────────────────────────┐
│ Reports erasing              │
│ ┌──────────────────────────┐ │
│ █            #01            │ │
│ ♦                          │ │
│    Erase this report?      │ │
│ Esc        All        Yes  │ │
└──────────────────────────────┘
```

Pressing Esc returns to previous menu. Pressing Yes will erase the chosen report, pressing All will delete all the stored reports.

3.5.3 Clock

```
┌──────────────────────────────┐
│ Clock                        │
│ ▶ Time            08:57:08   │
│   Date            06/29/04   │
│   Date format   mm/dd/yy     │
│                              │
│ Esc      Change      Data    │
└──────────────────────────────┘
```
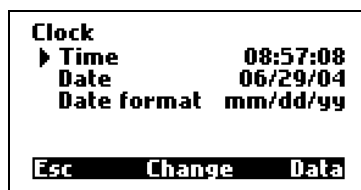
Here, the internal clock/calendar can be set.

Time

Time settings

Date

Date settings

Date format

The choice of date representation. User can choose between **Day – Month – Year** and **Month – Day – Year date** format

3.5.4 Service

The following screen appears when the option is opened:

```
┌──────────────────────────────┐
│ Service                      │
│   Info                       │
│ ▶ Control list               │
│   CO calibration             │
│   NOx calibration            │
│   Pressure calibration       │
│ Esc        OK        Data    │
└──────────────────────────────┘
```
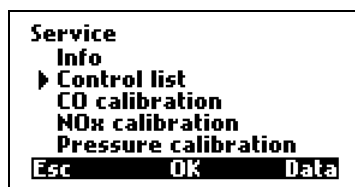
3.5.4.1 Info

The screen *INFO* shows some information about the instrument.

```
┌──────────────────────────────┐
│ GA12 info                 I  │
│  Software:          0.36     │
│  Serial No:      12221024    │
│  Last report:      #00027    │
│  NOx sensor:         Yes     │
│  %RH sensor:          No     │
│ Esc         II        Data   │
└──────────────────────────────┘
```

Using the II key displays the next **INFO** screen.

```
GA12 info                II
  Press. range:      20 hPa
  Fast printer           No
  XRAM                 32kB
  NiCd batteries:        No

 Esc          I        Data
```

3.5.4.2 Control list

The option **CONTROL LIST** shows all measured signals. This is of great use when searching for defects. The control list is displayed on two screens.

The following screen appears:

```
Control list              I
  Ta   24.8 4900.9 32763
  Ti   24.8 2719.3 18053
  Tg    ---  36494 32767
  NOx   0.0    Yes     47
  CO    0.0           -39
 Esc          II       Data
```

Using the II key displays the next **INFO** screen.

```
Control list             II
  O2     ---         18291
  P        0             3
  Ub   5.905         15126
  RH     ---     No  31232
  Calibration:          OK
 Esc          I        Data
```
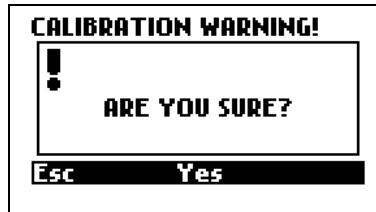
3.5.4.3 CO calibration

To calibrate the sensor, a calibration gas of known concentration is applied to the instrument. After a few minutes the signal is stable and can be stored as calibration value.

When the calibration value is stored it will automatically erase the previous value. If incorrect values are stored, then the instrument becomes practically useless for measurement purposes. *CALIBRATION* should only be opened if it is genuinely to be carried out and calibration gas is available.

The concentration of the calibration gas should, ideally, be similar to the expected concentration in the combustion gases.

The calibration gas should be applied for at least 4 minutes. After calibration of a sensor the instrument requires at least 15 minutes in fresh air to purge the system. Before the calibration procedure the following screen appears:

```
CALIBRATION WARNING!
!
          ARE YOU SURE?

Esc           Yes
```

Calibration procedure

After confirmation the following screen appears:

```
CO calibration
                Signal    ppm
Measured       -3256      0.0
Stored         21192   1498.0
▶ Concentration           1498
Esc       Change          OK
```

The screen has the following meaning:

- **Measured**   -   the currently measured signal from the sensor and the calculated gas concentration.
- **Stored** -   the previously stored signal and concentration.
- **Concentration**   -   the concentration of the calibration gas given in [ppm].

With the use of the **change** key the user can call up the screen where the concentration of the calibration gas can be set.

When the concentration has been set and confirmed with OK the instrument will automatically return to *CO Calibration.* Apply the calibration gas to the instrument and wait for a stable signal (approx. 3 – 4 minutes). Use OK to store the value. Before the value is permanently stored the next screen must be confirmed with YES. If there is any doubt as to the validity of the values, then the option can be left by pressing ESC.

3.5.4.4 NO calibration

The procedure is identical to the calibration with CO gas.

3.5.4.5 Pressure calibration

This procedure requires an accurate pressure meter and a precision pressure source.

When the calibration value is stored it will automatically erase the previous value. If incorrect values are stored, then the instrument becomes practically useless for measurement purposes. CALIBRATION should only be opened if it is genuinely to be carried out and the necessary equipment is available.

Calibration procedure

Open the option. After the warning note the following screen appears:

```
Pressure calibration
                Signal    Pa
Measured          16     1.6
Stored         15723  1532.0
▶ Pressure             1532
Esc      Change         OK
```

The lines have the following meaning:

- **Measured**   -   The signal currently supplied by the pressure sensor
- **Stored** -   The previously stored signal and calibration pressure.
- **Pressure**   -   Calibration pressure in [Pa].

With the use of the **change** key the user can call up the screen where the calibration pressure value can be set.

Apply the calibration pressure to the instrument and wait for a stable indication (approx. 1 minute). Press **OK** to store the value. **ESC** can be used to exit without storing.

Attention! Access to all calibrations can be locked via the PCGA12plus programme. The attempt to access the calibration screen will evoke the following screen:

```
!
!
        Option disabled...
```

3.6 Printer

```
Print?
  Averaged results        2
▶ Stored report           5
  Last screen

Esc         OK        Data
```

Pressing the printer key calls up this screen. The last measured values are kept in the memory and are hence available for the print out. On the right hand side the number of the display is a number that can be between 1 and 8.

The keys **left/right** can be used to change the value. This defines the printout layout. The programme **PCGA12** can be used to define the layouts 1 to 4. Layouts 5 to 8 are the default versions set at the factory. 5 and 6 are for current values, 7 and 8 for reports. The detailed information on how to define the printout layouts is given in the programme.

Fast results

The last measured values will be printed using the chosen layout.

Averaged results

The last calculated averaged results will be printed using the chosen layout.

Stored report

A report will be printed using the chosen layout.

Last screen

The content of the last screen displayed will be printed.

4   FLOW VELOCITY MEASUREMENT

The GA12 analyser is able to measure the differential pressure of the flue gases and can be equipped with a Pitot tube with which the flow velocity measurement can be performed. This value is necessary when calculating the mass flow velocity and the mass of pollutants emitted by the source in a particular period of time. The system calculates the values using the formula:

$$v\left[\frac{m}{s}\right] = 1.291 * \sqrt{\frac{T_{gas}[K]}{289} * \frac{100000Pa}{100000Pa + P_{stat}[Pa]} * P_{dif}[Pa]}$$
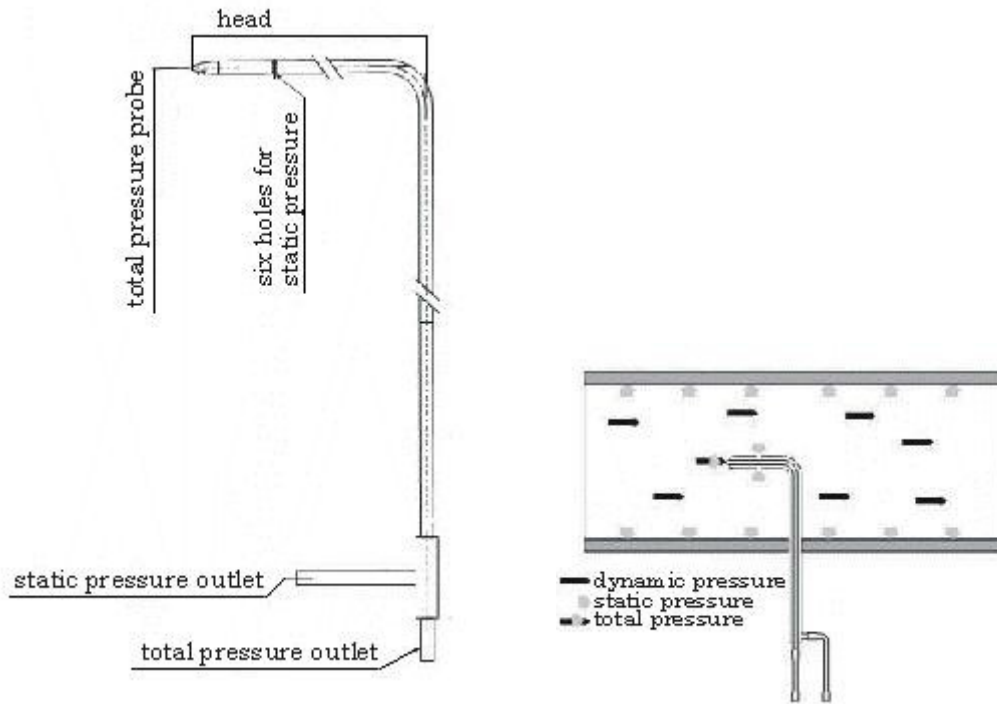
v – flue gas velocity [m/s]

1.291 – coefficient of the Pitot tube

T$_{gas}$ – flue gas temperature [K]

P$_{stat}$ – static pressure [Pa]

P$_{dif}$ – differential pressure [Pa]

The Pitot tube consists of two concentric tubes with one end bent at a right angle. The total pressure inlet is situated at the very end of the tube. The flue gases flow parallel to the bent end of the tube. The holes used for measuring the static pressure value are situated at the circumference of the transverse section of the bent end of the tube (see the picture above) which means they are perpendicular to the direction of the flue gas flow. The static pressure measurement can be performed as the flue gas flow causes a negative pressure to occur in the static pressure holes.

The tube must be connected to the analyser inlets (the total pressure outlet of the tube – to the analyser's differential pressure sensor inlet (+) and the static pressure outlet of the tube to the analyser's differential pressure sensor inlet (-)).

The GA12 analyser measures the difference between the values of the total and the static pressure (which means the differential pressure) and calculates the flue gas velocity on the basis of these measured values. The calculated value can be displayed on the results screen.

The results of the measurement performed with the use of a Pitot tube are correct provided that the analyser position is not changed after the beginning of the sensor zeroing process and both the device and the tube are held in the same (described above) position throughout the measurement process.

This measurement will only provide the flow velocity at a single point in the cross section of the flue gas channel, but at normal flue gas flow rates the velocity profile will be reasonably constant across the cross section. With use of the cross sectional area of the flue gas channel, the volume and hence mass flow rates can be calculated.

5   BASIC PRINCIPLES OF CALCULATING RESULTS

5.1   Quantities obtained from direct measurements (O_2, CO, NO, NO_2 or SO_2)

The values mentioned above are measured directly by means of independent electrochemical cells. The electrochemical cell indications are proportional to the gas concentration and given in ppm (parts per million) or percents.

5.2   Calculating the concentration of carbon dioxide

The volume concentration of carbon dioxide (expressed in [% vol]) is not obtained by direct measurement, but is calculated on the basis of measured oxygen concentration and the CO_{2max} parameter, characteristic for the given fuel.

5.3   Calculating the concentration of nitrogen oxides NO_x

In addition to nitric oxide NO, combustion gases contain also higher oxides of nitrogen - mainly NO_2. The concentration of nitrogen oxides expressed in [ppm] can be (with a high accuracy) defined as a sum of NO and NO_2 concentrations. It is generally assumed that nitric oxide NO contained in combustion gases makes up about 95% of the total amount of nitrogen oxides NO_x. **GA-12** calculates the total concentration of nitrogen oxides NO_x according to the following formula:

If the analyser is equipped with NO_2 sensor the NO_x concentration is the sum of NO and NO_2 concentrations taken from the direct measurements.

5.4   Concentration of "undiluted" carbon monoxide CO_u

To make the calculation of the carbon monoxide concentration in combustion gases independent of excess air with which the combustion process is conducted, the idea of "undiluted" carbon monoxide CO_u was introduced. The value of CO_u is calculated according to the formula below:

$$CO_u = CO \cdot \lambda$$

where:
CO   - volume concentration CO[ppm]
λ - excess air number

5.5 Absolute mass concentration of gas components

Absolute mass concentration is calculated from the concentration expressed in [ppm] using the factor A according to the following formula (here CO concentration):

where:

$CO[mg/m^3]$ - absolute CO mass concentration in combustion gas (at standard conditions).

$CO[ppm]$ - absolute CO volume concentration in combustion gas (from measurement).

A_{CO} - correction factor from table below:

Gas	$A\left[\dfrac{mg}{m^3 * ppm}\right]$
CO	1,250
NO	1,340
NO_x	2,056
SO_2	2,860
H_2S	1,520
Cl_2	3,220

Factors to correct concentration in [ppm] into mass concentration in [mg/m³] (at standard conditions 1013 hPa, 0ºC).

Mass concentration of nitrogen oxides (NOₓ) is calculated by the analyser (according to the standards) using the nitrogen dioxide (NO₂) factor.

Mass concentration calculated by GA-12 is comparable with the results obtained by other methods (or different types of analysers) only when b o t h c a l c u l a t i o n s   h a v e   b e e n   c a r r i e d   o u t   b a s e d   o n   t h e s a m e   s t a n d a r d   c o n d i t i o n s .

5.5.1 Mass concentrations relative to the concentration of oxygen in combustion gases

As well as absolute mass concentration, the mass concentration relative to oxygen concentration in the combustion gases is calculated. The concentration of a given component in relation to oxygen concentration is expressed by the following formula (as an example for CO value):

where:

CO_{rel} - CO concentration in relation to oxygen expressed in $[mg/m^3]$

    O_{2ref} - reference oxygen, conventional parameter (chosen by selecting fuel or entered independently from keyboard) expressed in [% vol]

    O_{2meas} - the measured concentration of O_2 in combustion gases expressed in [% vol]

    20.95%   - oxygen concentration in pure air

    CO   - the measured concentration of CO in combustion gases expressed in $[mg/m^3]$ (absolute mass concentration)

Using a similar formulae, the concentrations in relation to oxygen concentration of nitrogen oxides NO_x is calculated. The concentration related to oxygen concentration was introduced to make the evaluated concentration independent of the way the combustion process is carried out. The absolute value (expressed in [ppm]) can be lowered artificially in the combustion process with an increase in excess air (large amount of O_2 in combustion gases). It does not have to be a decrease of the total emission. The formula which calculates concentration related to oxygen takes into account the oxygen concentration of the combustion gases, making the results independent of the excess air factor.

The parameter O_{2ref} - reference oxygen is a standard value. Standards recommend different values of this parameter for various types of fuel. In the system **GA-12** the value of reference oxygen can be accepted automatically in the process of fuel selection (the so-called a u t o m a t i c reference oxygen choice) or entered by the operator from the keyboard (the so-called m a n u a l selection of reference oxygen). Relative mass concentration calculated from two different measurements are comparable only if t h e s a m e r e f e r e n c e o x y g e n a n d the s a m e s t a n d a r d c o n d i t i o n s have been used.

If the measured concentration is less then the reference oxygen then the relative concentration calculated according to the formula would be less than the value of the absolute concentration. Not to lessen the value artificially in such a case - when $O_{2meas} < O_{2ref}$ - relative concentration values are replaced by the analyser with absolute concentration values.

5.6 Calculating combustion parameters

Beside calculating gas component concentrations the analyser calculates some parameters describing the combustion process. The formulas for calculating combustion parameters are empirical formulas. **GA-12** analyser calculates the parameters of the combustion process according to the principles predicted by DIN standards.

The most important parameter is the amount of heat convected by combustion gases to the environment - the so-called stack loss qA. Stack loss in calculated on the basic of empirical formula known as Siegert's formula:

$$qA = \left(T_{gas} - T_{amb} \right) \bullet \left(\frac{A1}{CO_2} + B \right)$$

where:

qA - stack loss - the percentage of heat produced in combustion process, which is convected with the combustion gases.

T_{gas} - flue gas temperature

T_{amb} - the temperature of the boiler inlet air (it is assumed by the analyser to be the   ambient temperature)

CO_2 - the calculated (on the basis of oxygen concentration and CO_{2max}) amount of CO_2 in combustion gases, expressed in [% vol]

A1, B -Siegert factors characteristic for a given fuel type (see fuels table)

On the basis of the calculated stack loss the analyser estimates the efficiency of the combustion process η (notice the difference between η and boiler efficiency).

$$\eta \left[\% \right] = 100 \left[\% \right] - q\mathrm{A} \left[\% \right]$$

where:

η   - combustion efficiency

The above formula assumes that the only quantity decreasing combustion efficiency is stack loss. Thus it omits incomplete combustion losses, radiation losses etc. Because of this gross simplification in the formula above it should be remembered that the efficiency calculated in this way can not be treated as precise.

However, efficiency calculated like this is very convenient as a comparable parameter when regulating the furnace. The formula, though simplified, reflects precisely the tendencies of efficiency change, thus it is possible to observe whether the efficiency increases or decreases. It is sufficient information for the regulation process.

It is possible to take into account the efficiency reduction caused by incomplete combustion. This loss is represented by a quantity called the loss by incomplete combustion IL. It determines the percentage of energy loss caused by the presence of flammable gases (in this case mainly CO) in the combustion gases.

$$IL = \frac{\alpha \bullet CO[\%]}{CO[\%] + CO_2[\%]}$$

where:

CO, CO_2 - volume concentrations of CO and CO_2 in the combustion gases

α - the factor specific for a given fuel

Calculating IL enables correction of the previously calculated combustion efficiency. Then the so-called corrected efficiency η* is calculated (the difference between the combustion efficiency η and the loss by incomplete combustion IL):

$$\eta^*[\%] = \eta[\%] - IL[\%]$$

The last combustion parameter calculated by **GA-12** is the excess air factor λ. This factor expresses how many times the amount of air supplied to the boiler is larger than the minimum amount which is necessary to burn the fuel completely. The system calculates λ on the basis of the known CO_{2max} value for the given fuel and the measured concentration of CO_2 in the combustion gases using the formula:

The above formula may be transformed into the following form:

$$\lambda = \frac{20.95\%}{20.95\% - O_{2meas}[\%]}$$

5.7 Fuel parameters

The basis for determining the quantities describing the combustion process correctly is the knowledge of fuel parameters. **GA-12** analyser stores parameters for a set of fuels. These are called standard fuels. The table below presents parameters for all the standard fuels stored in the analyser's memory.

No	Fuel type	CO_{2max} [%]	A1	B	α	O_{2ref} [%]	Hu [MJ/UNIT]	Unit
1.	Light oil	15.4	0.5000	0.007	52	3	42.70	kg
2.	Natural gas	11.7	0.3700	0.009	32	3	35.90	m³
3.	Town gas	13.1	0.3500	0.011	32	3	16.10	m³
4.	Coke-oven gas	10.2	0.2900	0.011	32	3	17.40	m³
5.	Liquid gas	14.0	0.4200	0.008	32	3	93.20	m³
6.	BIO-Diesel	15.7	0.4567	0.005	52	3	41.80	kg

Parameters of fuels stored in the memory of GA-12 analyser.

Table shows the following parameters:

CO_{2max} - the maximum concentration of carbon dioxide in the combustion gas, a quantity specific for a given type of fuel. The parameter determines the amount of carbon dioxide in the combustion gases if the combustion process is carried out with excess air factor equalling 1.

A_1, B - factors which appear in Siegert's empirical formula

α - the factor used to calculate loss caused by incomplete combustion.

It should be assumed

α= 69 for solid fuels

α= 52 for liquid fuels

α= 32 for gaseous fuels

O_{2ref} -reference oxygen - the parameter used to calculate relative concentrations of components

Hu - fuel quality - the amount of energy emitted during complete combustion of 1 kilogram (or 1m3 in case of gas) of fuel.

5.8 The influence of fuel parameters on the accuracy of result calculations

As has already been mentioned, **GA-12** does not measure the concentration of carbon dioxide, but calculates it from the measured oxygen concentration and the CO_{2max} parameter. On the basis of CO_2 concentration calculated in this way, the stack loss, combustion efficiency and loss by incomplete combustion are calculated. Obviously, the fuel parameters (especially CO_{2max}), have a fundamental influence on calculations of combustion processes. The following results calculated by **GA-12** are affected by fuel parameters:

CO_2 contents   - depends on CO_{2max}

qA stack loss   - depends on CO2max, A1 and B

η and η^* - depends on CO2max , A1 and B

IL loss by incomplete combustion   - depends on CO2max and α.

$$\lambda = \frac{20.95\%}{20.95\% - O_{2meas}[\%]}$$

As formula above shows, the value of the excess air factor is independent of fuel parameters. The calculated results of gas quantities (except CO_2) and the results of temperature measurements and power quantities do not depend on fuel parameters either.

Please note that fuel quality HV does not appear in any formula. This parameter does not influence any measurement result shown by **GA-12**.

E L E C T R O N I C S