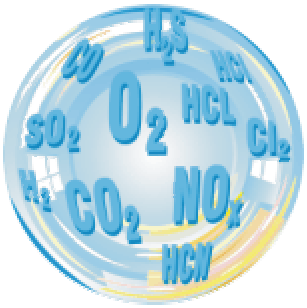


FLUE GAS ANALYSER
GA-12

Operating manual

Ver. 0.30

03/2004

madur®
ELECTRONICS

1 CONTENTS

1 CONTENTS 1
2 MAINTENANCE 2
3 OPERATION 3
3.1 Use of the keyboard 3
3.2 Basic operation 3
3.3 Results screens 4
4 MENU 5
4.1 Storing results 5
4.2 Action 6
4.3 Chart 7
4.3.1 Burner regulation – not yet available 8
4.4 Measurement parameters 8
4.5 Menu 9
4.5.1 Settings 9
4.5.2 Reports 9
4.5.3 Clock 9
4.5.4 Service 9
4.5.4.1 Info 10
4.5.4.2 Control list 10
4.5.4.3 CO calibration 10
4.5.4.4 NO calibration 11
4.5.4.5 Pressure calibration 11
4.6 Printer 11
5 BASIC PRINCIPLES OF CALCULATING RESULTS 13
5.1 Quantities obtained from direct measurements (O_2, CO, NO) 13
5.2 Calculating the concentration of carbon dioxide 13
5.3 Calculating the concentration of nitrogen oxides NO_x 13
5.4 Concentration of "undiluted" carbon monoxide CO_{undil} 13
5.5 Mass concentrations of gas components 13
5.5.1 Absolute mass concentration of gas components 14
5.5.2 Mass concentrations relative to the concentration of oxygen in combustion gases 14
5.6 Calculating combustion parameters 15
5.7 Fuel parameters 16
5.8 The influence of fuel parameters on the accuracy of result calculations 17

2 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

The gas system is protected by an in-line filter. The filter element will become dirty with use and should be changed when necessary. The water which 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 gas. We recommend that service be carried out every 12 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.

3 OPERATION

3.1 Use of the keyboard

Description of the keys

F1 - Left function key. Carries out the function shown on the display whilst the instrument is switched on.

F3 - Right function key. Carries out the function shown on the display whilst the instrument is switched on.

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

PRINT - Starts a print-out.

OFF - Switches the instrument off.

⬅ - On a results screen calls the option ***PARAMETER***, 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.

3.2 Basic operation

Getting started

Connect the individual parts of the instrument:

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

Switching on

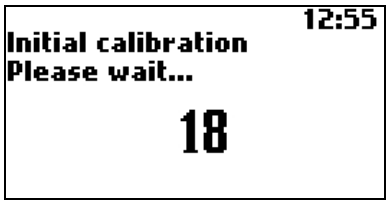
Check the filter before switching on. Clean or replace as necessary.

Zero calibration

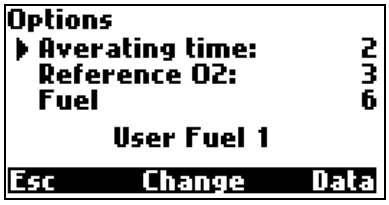
The instrument performs a zero calibration immediately after being switched on.

> **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.

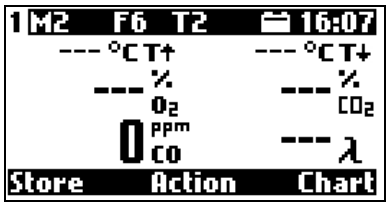


After the zero calibration the option ***PARAMETER*** opens automatically. Here the measuring parameters can be checked or changed. See also Pt. **Fehler! Verweisquelle konnte nicht gefunden werden.**



3.3 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.
- **M15** shows how many memory spaces are still available. In this case, 15 of the 16 reports are still empty.
- **F1** shows the chosen fuel. The instrument contains 6 fixed and 4 programmable fuels. These are numbered 0..9.
- **T180** 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.
- **16:39** 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 content of the individual results screens can be defined by the user. The necessary software, ”GA12control.exe”, 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: O2, CO, NOx und CO2
- 2 - Undiluted volumetric concentration of the gases. COu, NOxu

- 4 - Mass concentration of the gases:
  - absolute: COm, NOxm
  - relative, related to a defined level of rest oxygen: COrel, Noxrel
- 2 – Emission of the gases related to the energy value: ECO, ENOx
- 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

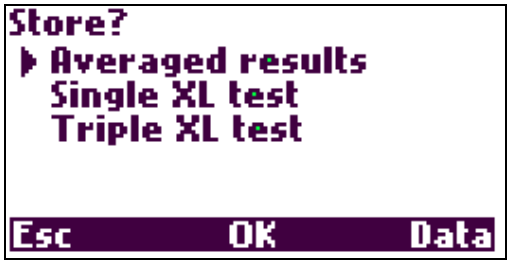
4 MENU

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

- Store – Left function key.
- Action – Centre function key.
- Graphic – Right function key.
- Parameter – Arrow left.
- Menu - Arrow right.
- Print – Key with a page shown on it.
- Switch off – Pressing the round, red key will switch the instrument off completely.

4.1 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:



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. The averaging times that can be set under **parameter II** are 1, 5, 10, 15, 20 and 30 minutes.

Triple XL test

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

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.

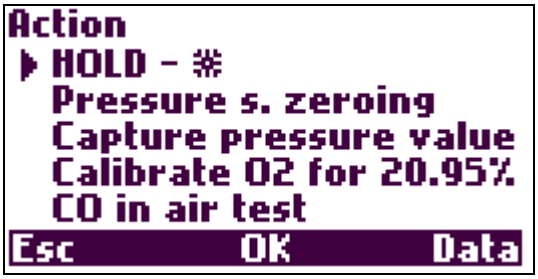
If the results are to be stored, then the instrument will request a customer number (identification number of the report). This number will appear on the report.

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

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 #0029 is not the report number (1…16), it is the activity counter which is automatically attached to the report by the instrument.

4.2 Action

This useful tool comprises a list of simple commands which will all be confirmed by the instrument if activated.
Pressing the centre function key on the results screens will open this option.



HOLD - *

The present measurement values are frozen and the screen will spring automatically to the frozen values. Pressing the centre function key again will end the freezing of the values and the instrument will return to showing the present values.

Pressure s. zeroing

This sets the pressure sensor to zero. 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 measured value for pressure is stored in a temporary memory. This will be included in the next print-out or will be stored with the next report under **pressure**.

Calibrate O2 for 20.95 %

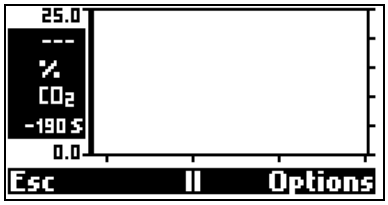
The GA-12 has the possibility of calibrating the O2 sensor with clean air in order to increase the accuracy of measurement when the instrument has been in use for some time. Do not forget to remove the probe from the stack and wait for a stable reading.

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 appear in the next print-out or be stored with the next report as "Ambient CO".

4.3 Chart

The instrument stores the last 90 values of the 2 second averaging in the RAM. Hence 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 100).
- Current value or, when the marker is activated, the marker value (here 24.0).
- The unit (here °C). This appears automatically with the variable.
- The variable (here Ta). The arrow up/down keys can be used to scroll through the variables.
- Marker time (here –128s). This means the marker stands on the value that was recorded 128 seconds earlier.
- Minimum value of the Y axis (here –20)

The menu bar:

ESC

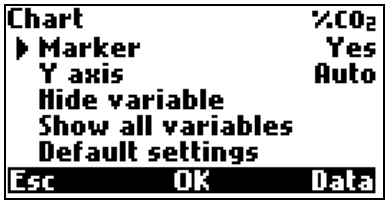
Leave the Chart and return to the results screen.

Sign II

Chart for boiler adjustment – 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 according to the measured values.
- Manual – 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 Charts. 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 Charts.

Default settings

After confirmation with OK the instrument will show some important measured and calculated results: O2, CO, ETA, Lambda, Tgas

4.3.1 Burner regulation – not yet available

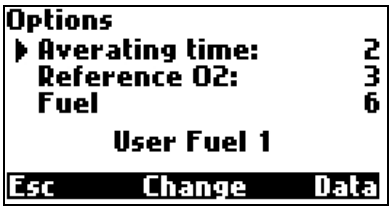
This option allows the combustion process in a burner to be visualised. Three variables which define the combustion process are shown graphically.
These are:

- O2 – oxygen concentration
- SL – Stack loss
- Lambda – Excess air

All three curves are shown together on a diagram. This means that the dynamic connection between all the variables is easily seen and the air inlet can be adjusted for optimal combustion. All three curves cross at a common point. This is the present working point of the burner.
The curve for O2 is fixed. This will not change when adjustments are made. The diagram shows concentrations of 0…10 %.
The SL (stack loss) is a straight line which will move up or down when adjustments are made. This is shown in the range 0…20 %.
The Lambda value is a vertical straight line, which will move left/right during adjustment. This is shown in the range 1…2.
The user can also set two markers to define the desired range for Lambda. If the value becomes larger than the right marker, then an arrow to the left will appear under the X axis meaning “Reduce air flow”. If an arrow to the right appears, then Lambda is too small and this means “Increase air flow”.
On the right of the display the CO concentration is shown as a bar chart.
Burner regulation can be reached from ***MENU*** as follows:

4.4 Measurement parameters

The arrow left will access ***Parameter*** from the results screens.
The following screen appears:



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

The following reference oxygen values can be set using the function key ***change*** or the arrow left/right:
3 – 5 – 6 – 11 % O2

Fuel

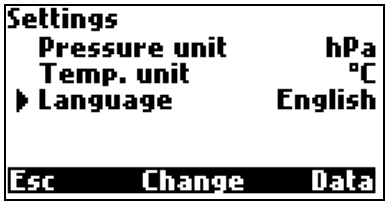
The following 6 fuels can be set using the function key ***change*** or the arrow left/right:
Light oil
Natural gas
Town gas

Coke-oven gas
Liquid gas
Bio-diesel

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

4.5 Menu

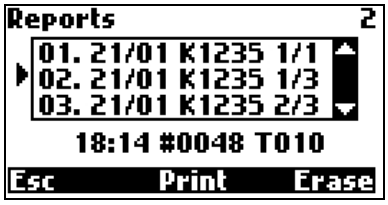
4.5.1 Settings



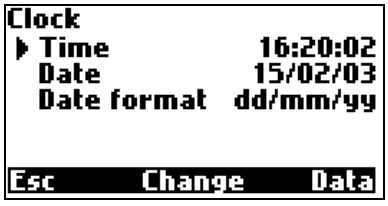
The instrument is pre-programmed with a number of languages.

4.5.2 Reports

This option allows al reports to be deleted. It is reached as follows from ***STORE***:



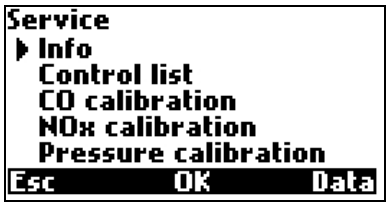
4.5.3 Clock



Here, the internal clock/calendar can be set.

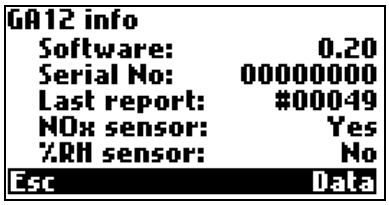
4.5.4 Service

The following screen appears when the option is opened:



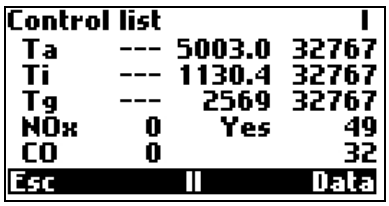
4.5.4.1 Info

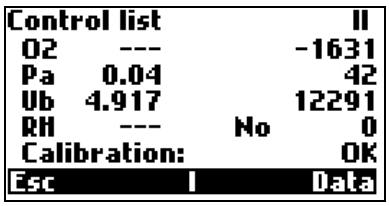
The screen ***INFO*** shows some information about the instrument.



4.5.4.2 Control list

The option ***CONTROL LIST*** shows all measured signals. This is of great use when searching for defects.
The following screen appears:





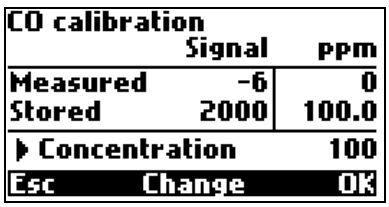
4.5.4.3 CO calibration

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.

Calibration procedure
Open the option. The following screen appears:



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 in [ppm].

Using **change** 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.

4.5.4.4 NO calibration

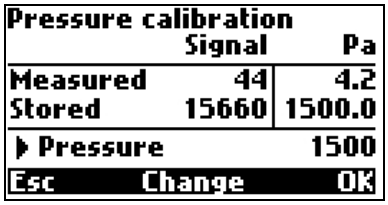
The procedure is identical to the calibration with CO gas.

4.5.4.5 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. The following screen appears:



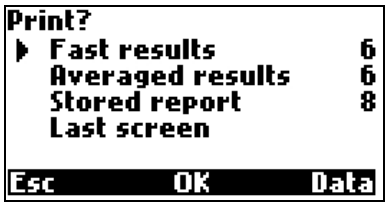
The screen has the following meaning:

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

The key **change** can be used to change the value of the calibration pressure.

After entering the value and confirming with **OK** the instrument will automatically return to **Pressure calibration**
Apply the calibration pressure to the instrument and wait for a stable indication (approx. 1 minute). Press **OK** to store the value, The next screen must then be answered **YES** to complete the calibration. **ESC** can be used to exit without storing.

4.6 Printer



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 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 is the definition of the print layout used for the values. The programme **GA12control** can be used to set 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 method of changing the layouts is described 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.

5 BASIC PRINCIPLES OF CALCULATING RESULTS

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

In direct measurements the temperature values and also the concentration of those gas elements which are detected by independent electrochemical sensors are obtained. The electrochemical cell indications are proportional to the volume concentration of the detected elements expressed in [ppm] (parts per million).

The following quantities are obtained by means of direct measurement:

- ❒ flue gas temperature T gas and ambient temperature, expressed in [^{O}C]
- ❒ volume concentration of CO [ppm]
- ❒ volume concentration of NO [ppm]
- ❒ volume concentration of O_2 [%]

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.

Formula 1 shows the formula according to which the analyser calculates volume concentration of CO_2:

❶
$$CO_2 = CO_{2max} \bullet \left(1 - \frac{O_{2meas}[\%]}{20.95\%}\right)$$

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) **GA-12** does not have the nitrogen dioxide sensor, only the nitric oxide sensor NO. But it is possible to calculate the NO_2 content on the basis of the measured NO. 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:

❷
$$NO_X[ppm] = \frac{NO[ppm]}{0.95}$$

5.4 Concentration of "undiluted" carbon monoxide CO_{undil}

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_{undil} was introduced (it is also called the CO concentration calculated for 0% O_2). The value of CO_{undil} is calculated according to the formula below:

❹
$$CO_{undil} = CO \cdot \lambda$$

where:

CO - volume concentration CO[ppm]

λ – excess air number

As can be seen, the concentration of "undiluted" CO is the hypothetical concentration that would have been formed if the same amount of carbon monoxide had appeared in combustion gases when burning without excess air (where $\lambda = 1$, so $O_2 = 0\%$).

5.5 Mass concentrations of gas components

GA-12 also makes calculations of mass concentration expressed in [mg/m3] from the concentration expressed in [ppm]. Mass concentration of gas elements depends on the gas pressure and temperature. To make comparison of results possible, the idea of standard conditions was introduced, that is standard temperature and pressure values at which the mass concentration of the elements is calculated. In GA-**12** system standard conditions of 1000 hPa and 0^{O}C were taken.

The analyser indicates two different values expressed in [mg/m^3], they are the so called absolute mass concentration and mass concentration relative to oxygen. These values are often confused - in the next section the way they are calculated and the differences between them are explained.

5.5.1 Absolute mass concentration of gas components

Absolute mass concentration defines how many milligrams of a given gas is contained in 1m^3 of combustion gas at standard conditions (1000 hPa, 0^{o}C). The concentration value is calculated from the concentration expressed in [ppm] using the factor A from table 6. The following formula shows how the absolute mass concentration is calculated (here CO concentration):

❺ $$CO\left[\frac{mg}{m^3}\right] = CO[ppm] \cdot A_{CO}$$

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 6.

Gas	$A\left[\frac{mg}{m^3 * ppm}\right]$
CO	1.250
NO	1.340
NO_X	2.056

Tab. 6: Factors to correct concentration in [ppm] into mass concentration in [mg/m3] (at standard conditions 1000 hPa, 0^{o}C).

Note: mass concentration of nitrogen oxides (NO_x) is calculated by the analyser (according to the standards) using the nitrogen dioxide (NO_2) factor.

Mass concentration calculated by **GA-12** is comparable with the results obtained by other methods (or different types of analysers) only when both calculations have been carried out based on the same standard conditions.

5.5.2 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):

❻ $$CO_{rel}\left[\frac{mg}{m^3}\right] = \frac{20.95\% - O_{2ref}}{20.95\% - O_{2meas}} \cdot CO\left[\frac{mg}{m^3}\right]$$

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 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 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 have been used.

Note: **If $O_{2meas} < O_{2ref}$ then relative concentration CO_{rel} calculated from formula ❻ is less than absolute concentration. I n s u c h a c a s e , t h e a n a l y s e r r e p l a c e s t h e v a l u e o f r e l a t i v e c o n c e n t r a t i o n w i t h t h e v a l u e o f a b s o l u t e m a s s c o n c e n t r a t i o n .**

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 chimney loss (stack loss) S_L. Chimney loss in calculated on the basic of empirical formula known as Siegert's formula:

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

where:

S_L - chimney 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 - factors characteristic for a given fuel type (see Table 7)

Based on the calculated chimney loss the analyser estimates the efficiency of the combustion process η (don't confuse it with boiler efficiency)

❽
$$\eta = 100\% - S_L$$

where:

η - combustion efficiency

The above formula assumes that the only quantity decreasing combustion efficiency is chimney loss. Thus it omits incomplete combustion losses, radiation losses etc. Such a simplification is a result of the inability to measure the size of other losses with the gas analyser. 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. The loss caused by incomplete combustion is calculated on the basis of measured CO concentration in the combustion gases according to the following formula:

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

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 (formula 8) combustion efficiency. Then the so-called corrected efficiency η^* is calculated:

$$\eta^* = \eta - IL$$

The last combustion parameter calculated by **GA-12** is the excess air factor ⌧. 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 the l factor on the basis of the known CO_{2max} value for the given fuel and the calculated concentration of CO_2 in the combustion gases using the formula:

❿
$$\lambda = \frac{CO_{2max}}{CO_{2meas}}$$

The above formula may be transformed with the use of formula ❶ into the form:

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

5.7 Fuel parameters

The basis for correctly determining the quantities describing the combustion process is the knowledge of fuel parameters. **GA-12** analyser has stored parameters for several standard fuels. Table 7 presents parameters for all the possible analyser fuels**.** Not all of these are installed as standard.

No	Fuel type	CO_{2max} [%]	A1	B	α	O_{2ref} [%]	Vatr [m³]	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

Tab. 7: Parameters of fuels stored in the memory of GA-12 analyser.

Table 7. 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 l equal 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 (formula 4). It is a standard quantity. In the table, it has been assumed that as in DIN standards that it is: 11% - for solid fuels and 3% for gaseous and liquid ones.

HV - fuel quality - the amount of energy emitted during complete combustion of 1 kilogram (or $1m^3$ 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 basis of CO_2 concentration calculated in this way, the chimney 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

S_L chimney loss - depends on CO_2max, A1 and B

η and η^* - depends on CO_2max , A1 and B

IL loss by incomplete combustion - depends on CO_2max and α.

As formula ⑩ 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.**

madur®

E L E C T R O N I C S